ANL-7641

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Argonne National Laboratory

PHYSICS DIVISION SUMMARY REPORT

April—September 1969

ANL-7641
Physics

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

PHYSICS DIVISION SUMMARY REPORT

April—September 1969

Lowell M. Bollinger, Division Director

Preceding Summary Reports:

ANL-7512, April-December 1968
ANL-7570, January-March 1969
ANL-7620, Annual Review

FOREWORD

The Physics Summary is issued several times per year for the information of the members of the Division and a limited number of other persons interested in the progress of the work. It includes short reports on highlights of the current research, abstracts or short summaries of oral presentations at meetings, abstracts of papers recently accepted for publication, and publication notices of papers appearing in recent journals and books. Many of these reports cover work still in progress; the results and data they present are therefore preliminary, tentative, and often incomplete.

The research presented in any one issue of the Summary is only a small random sample of the work of the Physics Division. For a comprehensive overview, the reader is referred to the ANL Physics Division Annual Review issued each summer, the most recent being Argonne National Laboratory Report ANL-7620, which reports research in the year ending 31 March 1969.

The issuance of these reports is not intended to constitute publication in any sense of the word. Final results will be submitted for publication in regular professional journals or, in special cases, presented in ANL Topical Reports.

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These research highlights are Physics Division contributions to the Physical Research Monthly Report which the Laboratory Director's Office sends to the Division of Research of the U. S. Atomic Energy Commission. They report interesting work that is currently in progress or that has just been completed.

THE 4-MV DYNAMITRON FACILITY

R. Amrein, A. S. Langsdorf, Jr., F. P. Mooring,
W. G. Stoppenhagen, and J. R. Wallace

The new 4-MV Dynamitron ion accelerator, delivered to Argonne in the fall of 1968, has now been installed and has successfully passed all of the specified acceptance tests. The installation of the associated beam-handling and energy-analyzing systems has been completed and the new facility is now in use.

The replacement of our 20-year-old Van de Graaff accelerator by one with the same nominal voltage rating was motivated by an urgent need for a much larger beam current. Further progress in many aspects of fast-neutron spectroscopy depends upon a substantial increase in available neutron yield; and, since this yield is directly proportional to beam current, the need for a high-current accelerator becomes acute. The commercially available Dynamitron satisfies all immediate needs, and has the reserve potential to meet the expanding needs of the future.

The terminal of the Dynamitron is charged by a cascaded-rectifier system consisting of 96 stages of rectification whose dc outputs are electrically connected in series. The ac input is supplied at 120 kHz to each stage in parallel by direct capacitive coupling to a pair of large electrodes called dees. The parallel power feed distinguishes the new accelerator from the better known Cockcroft-Walton generator. It also provides an effective low internal impedance for the power source so that it has a moderate voltage drop under load.

Because of the relatively high frequency at which this system operates, the load-dependent ripple impressed on the terminal is quite small although the capacitively stored energy is no greater than that in a Van de Graaff accelerator. In contrast, other dc rectifier-type accelerators require additional capacitance to reduce terminal ripple and the larger stored energy increases the hazard of damage during sparkover.

The original intention was to install the Dynamitron where our old 4-MV Van de Graaff accelerator had been. However, as was reported in the Physics Division Summary Report ANL-7512, Apr.—Dec. 1968, it soon became obvious that the new machine should be installed in the basement of the Van de Graaff wing of the Physics Building.

During the summer of 1968, the area in which the Dynamitron is now housed was modified in preparation for its installation. The floor of the experimental area was lowered 4 ft and a concrete floor designed to support the anticipated loads to be imposed by the experimental equipment was poured. New tracks for the pressure vessel were laid. The electrical and water distribution systems were rerouted. Those shield walls that would not interfere with the installation of the Dynamitron were stacked. By the early fall of 1968, all alterations that could be made prior to the actual installation of the new accelerator were complete.

The Dynamitron was delivered on 2 October 1968. Radiation Dynamics, Inc., the vendor, also contracted to install the accelerator and to supply a gas-transfer system and a system for providing chilled water to cool the accelerator and its peripheral equipment. These systems and the Dynamitron were installed concurrently. Simultaneously, Argonne personnel were trained in the operation, maintenance, and basic principles of the Dynamitron.

By the middle of December the installation of the various systems had been completed, and on 17 December 1968 the Argonne Dynamitron was first operated. By 20 December it reached a terminal voltage of 4 MV. The various tests continued and the minor problems that arose were corrected during the month of January. On 28 January 1969 a hydrogen-ion beam with a current in excess of 1 mA and with a particle energy above 4 MeV was held on target for more than 2 hours.

The beams of hydrogen ions accelerated to date have ranged up to 1.6 mA. A Faraday cage which intercepted 99.9% of the total solid angle was used to collect the beam current and a meter accurate to 2% of full scale was used to measure the current. The Faraday cage was not biased during the measurements; however, it was demonstrated that a bias voltage did not affect the measured results. An aperture, 2.5 cm in diameter, was placed in front of the Faraday cage and the current to the aperture was monitored. The aperture current was kept below (usually much below) 10% of the total ion beam current at all times.

The pressure in the drift tube and the Faraday cage was kept below 1×10^{-6} Torr during all measurements of beam current. Thus ionization of the residual gas should not have perturbed the results, and the fact that the application of a bias voltage on the Faraday cage did not alter the measured beam current confirms that results were not affected by gas ionization.

During the acceptance tests the ion beam was not mass analyzed. However, experience with similar duo-plasmatrons suggests that, with the operating conditions used during the acceptance tests, probably more than 50% of the ions in the beam were protons. Ions were accelerated to energies up to 4.2 MeV. The energy was determined by measuring the current through a resistance string connected to the high-voltage terminal of the Dynamitron. The $Li^7(p,n)Be^7$ and $Cu^{65}(p,n)Zn^{65}$ thresholds were used to calibrate the energy scale.

Initially, the energy spread in the beam exceeded that permitted by specifications. Investigation showed that the principal source of the energy spread was a 120-kHz ripple impressed on the terminal by the charging system. However, a variable trimmer capacitor installed between the lower dee and ground allowed the amplitudes of the voltages on the dees to be more nearly balanced and reduced the terminal ripple by a large factor. The present indications are that the energy spread in the beam has been reduced to less than ±2 keV.

All acceptance tests were successfully completed by 19 February 1969. Of the five 4-MV Dynamitron accelerators now in the field, the Argonne machine (the last to be delivered) was the first to successfully pass all acceptance tests. After a short conditioning period, the accelerator can be raised to full current and voltage very rapidly. This behavior is not characteristic of most other electrostatic accelerators, including all other 4-MV Dynamitrons. The reason for this property of the Argonne machine is not understood.

In meeting the acceptance tests, the new accelerator has produced a well-focused beam of positive ions in excess of 1 mA from 1.5 to 4 MeV. A similar machine has already delivered 3 mA of positive ions. The power supply is adequate to generate an ion beam as large as 10 mA at 4 MeV. Thus the machine has the potential for producing much larger beam currents. However, at present a principal deterrent to the production of larger beam currents is the loading of the power supply by the so-called corona current. This current, which may be as much as 5 times the beam current, arises from ionization of the insulating gas by x rays, which at maximum beam current and voltage reach a dose rate of 100 R/hr at a point outside the pressure vessel and near the high-voltage terminal. Thus before larger beam currents are generated, it is imperative that the production of x rays be reduced.

The x rays are generated by electrons that are produced in the accelerator tube and then are accelerated back to the terminal. There are at least five known ways to reduce the effects of x-ray production. (1) Use heavy metal around the source spots to absorb x rays before they enter the insulating gas. (2) Reduce the yield of x rays per electron by placing a light metal such as beryllium wherever electrons impinge. (3) Improve the vacuum inside the accelerator tube to reduce the number of electrons generated. (4) Trap the electrons by electric or magnetic fields before they acquire enough energy to produce very hard x rays. (5) Use mass analysis in the terminal to prevent undesirable ion species from entering the accelerator tube where they would cause needless ionization and consequently additional backstreaming of electrons. With the exception of (4), all of these methods are relatively simple (if not pushed too far) and will be used in an attempt to increase the maximum current available. In the long run, method (4) offers the greatest prospects for improvement.

In addition, the energy spread of the ion beam can be still further reduced. The present ±2-keV spread in energy is caused mainly by voltage ripple impressed on the terminal from various power sources. Preliminary studies of the various sources of the ripple indicate that with moderate effort the energy spread in the beam can be reduced by approximately another order of magnitude.

A beam-switching magnet has been installed to direct the beam into any one of thirteen beam lines. Two separate electrostatic analyzer systems have been installed. Ions of mass number 1, 2, 3, 4, 12, or 16 can be used in experiments, while the energy of the ions is monitored by measurements of any one of the other masses.

The permanent shield walls have now been completed. The basic components of a radiation-alarm and safety-interlock system were designed and installed so that the accelerator tests could be carried out safely. Information about radiation levels was obtained during the performance tests and will be used in extending the system. A new data-recording room and computer center are now available. The experimental program making use of the new machine is now under way.

INSTALLATION OF THE SPLIT-POLE MAGNETIC SPECTROGRAPH AT THE TANDEM VAN DE GRAAFF ACCELERATOR

John R. Erskine

A split-pole magnetic spectrograph has recently been installed at the Tandem Van de Graaff accelerator, and use of this very capable instrument in research has begun. This sophisticated, new instrument (designed by H. A. Enge[1] from M.I.T.) will replace a Browne-Buechner magnetic spectrograph which has served the Physics Division well since 1963.

A schematic view of the new instrument is shown in Fig. 1. The device is described as a split-pole spectrograph because it has two separate pole pieces surrounded by a single magnetizing coil. The purpose of the split is to provide second-order double

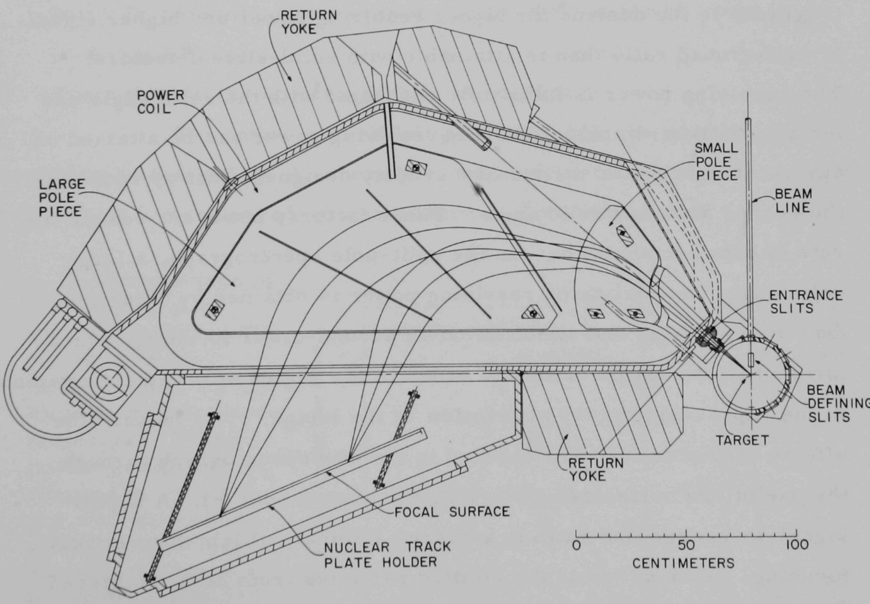


Fig. 1. Top view of the split-pole magnetic spectrograph.

[1] J. E. Spencer and H. A. Enge, Nucl. Instr. Methods 49, 181 (1967).

focusing over a broad range of energies. As can be seen in the figure, the entrance and exit boundaries of the small pole are circular in shape whereas the boundaries of the large pole are straight. These surfaces have been very carefully adjusted to give the outstanding performance of this spectrograph.

The new spectrograph is superior to the old one in many ways: energy resolution, solid angle of acceptance, maximum particle energy analyzed, range of energies simultaneously recorded, signal-to-background ratio, and ease of use. It can be moved continuously under a vacuum from a scattering angle of 0° to 160°. Charged particles emanating from the target are detected at the focal surface inside the camera with either nuclear emulsions or electronic position-sensitive detectors.

The principal justification for building magnetic spectrographs is the demand for higher resolving power and higher signal-to-background ratio than is attainable with solid-state detectors. The resolving power is intimately connected with the solid angle and the source area; in principle, any resolving power can be attained on any spectrograph, no matter how crudely designed, just by reducing the source area and solid angle. These factors, however, reduce the rate of data accumulation. In the split-pole spectrograph, a large solid angle that maintains resolving power is obtained by using two-direction focusing and simultaneously second-order focusing, which means that the terms of second order in the angles of acceptance vanish in the expression for the aberration of the image. The undesirable effects of source size are reduced in the new spectrograph through the use of low horizontal-plane magnification (about $\frac{1}{3}$). A higher signal-to-background ratio is achieved automatically by the vertical focusing, which prevents the emitted particles from being scattered from pole surfaces and thereafter reaching the detector.

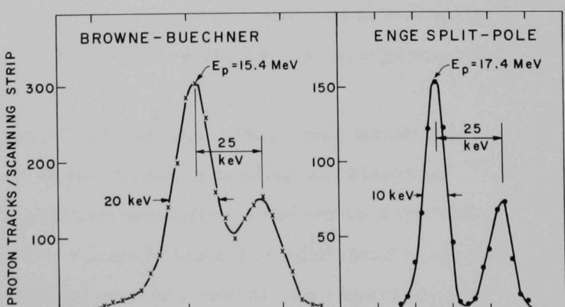
Various refinements in design make the new spectrograph exceptionally precise and at the same time unusually easy to use.

The more important properties of the instrument are:

1. The largest mass-energy product that can be bent by the spectrograph is about 95 amu-MeV.
2. An over-all energy resolution $E/\Delta E$ of 2000 can be attained at 2 msr solid angle with a $\frac{1}{2}$-mm-wide beam spot.
3. The ability to correct for Doppler broadening of lines, especially important for targets of light nuclei, is built into the plate-holder support mechanism.
4. Tapered poles with rounded corners are used to keep the magnetic field as uniform as possible and to minimize saturation effects.
5. The uniformity of the magnetic field is improved with a homogenizing air gap and a floating-pole-piece design, which keeps distortions in the yoke from being transmitted to the pole pieces.
6. The plate-camera system has a mechanical uncertainty that is small (0.15 mm) compared to the width of the detected peaks (0.4 mm FWHM).
7. The weight of the spectrograph is about 32 tons.

The improved resolving ability of the new spectrograph is demonstrated in Fig. 2, where preliminary data obtained with the new instrument are compared with data taken earlier with the old

Fig. 2. Comparison of the same proton groups recorded with the old Browne-Buechner and the new Enge split-pole spectrographs. These proton groups correspond to the first and second excited states in W^{185} produced by means of the $W^{184}(d,p)W^{185}$ reaction at bombarding energies of 12 and 14 MeV.



Browne-Buechner spectrograph. The over-all resolution achieved in these new measurements is more than twice that achieved in the earlier measurements.

An improvement in resolution of the magnitude shown in Fig. 2 can have a major impact on the usefulness of the measured spectra, so that the new split-pole spectrograph will make new kinds of experiments possible with the tandem accelerator. It will also greatly improve the precision and the ease of collecting data. Thus the new spectrograph, which will be used in at least 25% of the experiments at the tandem, will considerably enhance the research capability of the entire accelerator facility.

A second split-pole spectrograph was installed at the 60-in. cyclotron during the summer and is now coming into use.

THE (He^3,t) REACTION AND MULTIPOLE STUDIES OF TWO-BODY SPECTRA

R. C. Bearse, J. R. Comfort, J. P. Schiffer, M. M. Stautberg, and J. C. Stoltzfus

Measurements at the tandem Van de Graaff suggest that the (He^3,t) reaction is very selective in that the final states populated in the target nuclide are almost exclusively those describable as a neutron hole coupled to a proton. The proton and neutron hole then interact to generate a spectrum of states whose energies reflect the characteristics of basic two-particle nuclear forces. The (He^3,t) reaction leading to these states yields a very distinctive set of angular distributions. Recent studies of the reaction $Zr^{90}(He^3,t)Nb^{90}$ demonstrate these effects with clarity.

In the framework of the simple shell model, the first 40 protons and 40 neutrons of Zr^{90} completely fill all orbits through the 1f-2p major shell. The remaining ten neutrons fill the entire $g_{9/2}$ neutron orbit. The (He^3,t) reaction can be viewed as exchanging a $g_{9/2}$ neutron with a $g_{9/2}$ proton. There are ten possible states in Nb^{90} with such a configuration; they have spins from 0 to 9, inclusive, and positive parity. One of these, the $J^{\pi} = 0^+$ state, is the analog of the Zr^{90} ground state and lies at high excitation energy. Its energy has been estimated to be 5.03 MeV. Hence, at low excitation energies in Nb^{90}, one might expect to observe nine states that are populated strongly by the (He^3,t) reaction.

A Zr^{90} target, 0.21 mg/cm^2 thick, was bombarded with a 21-MeV He^3 beam from the Argonne tandem accelerator. Tritons were detected by a position-sensitive solid-state detector placed in the focal plane of the recently installed split-pole magnetic spectrograph. The experimental spectra reveal, as expected, that nine states were strongly populated at low excitation energies. A number of other states were also seen, but with much smaller cross

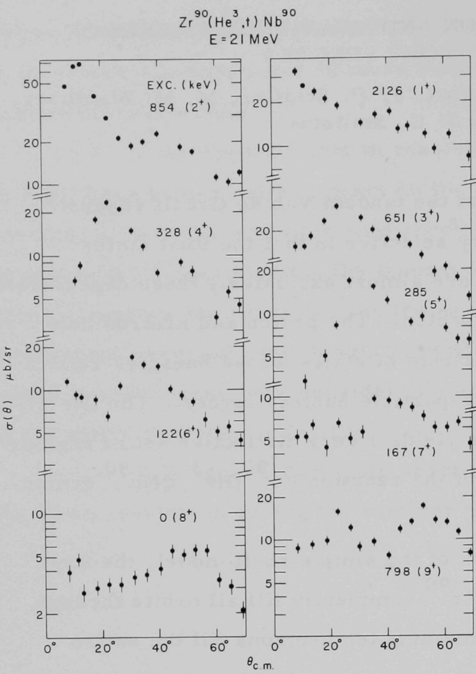


Fig. 3. Angular distributions for the $Zr^{90}(He^3,t)Nb^{90}$ reaction to strongly populated final states thought to be members of the $(g_{9/2})^2$ multiplet. The tentative 7^+ and 9^+ assignments of the previously unobserved levels at 167 and 798 keV are inferred from the systematic shift of the principal maximum towards larger angles as the spin value increases.

sections. The angular distributions for all states were extracted, those for the nine strongest states having distinctive shapes being shown in Fig. 3. The excitation energies and assumed spins are also shown.

Previous work on the beta decay of Mo^{90} had suggested a level scheme and established the spins of most of the states in Fig. 3. The angular distributions from the (He^3,t) reaction display a systematic pattern which suggests possible spin assignments. In keeping with the usual behavior of direct reactions, the position of the principal maximum slowly moves towards larger angles as the angular-momentum transfer increases. The spins so assigned are completely consistent with the beta-decay work. The levels at 167 and 798 keV, not seen before, are tentatively identified as 7^+ and 9^+ states, respectively. The fact that the nine states are enhanced by the (He^3,t) reaction clearly suggests that they are all members of the multiplet of the $(g_{9/2})^2$ configuration.

The energies of the states of the multiplet are determined by the interaction between the proton and the neutron hole. This spectrum can be expanded in Legendre polynomials involving the angle between the particle and hole orbits. A plot of the energy of each state against its spin value can thus be interpreted as a type of "angular distribution" and can be represented by a multipole expansion into Racah coefficients. The coefficients of the expansion, β_k (k = 0 to 9), are taken as the descriptive parameters.

These coefficients can also be calculated from various nuclear forces. It is known that the dominant interaction between two particles has a very short range. Indeed, one can assume a delta-function force (which allows an interaction only when the particles are at the same point) and obtain a set of β_k. These generally agree with the present data, except for the quadrupole (k = 2) coefficient (and the odd-k coefficients to a lesser extent). This same feature has also been noticed in the Sc^{48} spectrum, which is generated by the $(f_{7/2})^2$ configuration. However, excellent agreement has been obtained

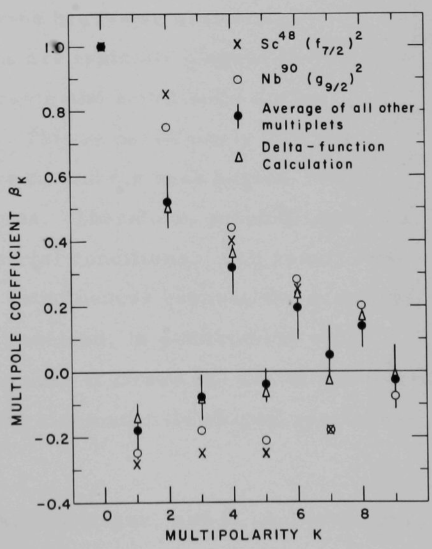


Fig. 4. Comparison between the multipole coefficients β_k obtained in different ways. The values extracted from our $(f_{7/2})^2$ spectrum in Sc^{48} and $(g_{9/2})^2$ spectrum in Nb^{90} are shown by crosses and open circles, respectively, the averages of the coefficients extracted from all other known two-body spectra are shown as solid circles, and the calculated coefficients for a delta-function force with spin exchange are shown as triangles.

between experiment and the delta-function calculations for multipoles that are generated by two particles in different shell-model orbits, as is shown in Fig. 4.

A report on this work has been published in Physical Review Letters.[1]

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[1] R. C. Bearse, J. R. Comfort, J. P. Schiffer, M. M. Stautberg, and J. C. Stoltzfus, Phys. Rev. Letters <u>23</u>, 864 (1969).

HEAVY-ION SCATTERING

R. H. Siemssen, H. T. Fortune, G. C. Morrison, A. Richter, J. W. Tippie,* and J. L. Yntema

The recent observation[1] of pronounced gross structure in the excitation function for the scattering of ^{16}O by ^{16}O has stimulated a renewed interest in heavy-ion elastic scattering. In particular, it has led to the suggestion that the potential between a heavy ion and a nucleus is of the molecular type—i.e., it is very shallow and has a repulsive core. In view of the widespread interest in the subject, we have undertaken an extensive experimental investigation of heavy-ion scattering for a variety of projectiles and targets and for the range of energies accessible to the FN Tandem. The objectives of the program are (a) to determine whether or not gross structure like that for $^{16}O + {}^{16}O$ scattering is present in other nuclear systems, (b) to establish a consistent heavy-ion—nucleus potential whose parameters vary systematically from nucleus to nucleus and with energy, and (c) to search for conclusive evidence that a molecular-type potential must necessarily be invoked to describe heavy-ion scattering.

Heavy-ion experiments are typically plagued by low counting rates because of the thin targets and small solid angles required for good energy resolution. This is particularly true for energies well above the Coulomb barrier and for back angles, which are involved in the present experiments. Therefore, much thought has been given to optimizing the experimental conditions. The associated-particle method, in which kinematic coincidences between the scattered particle and the recoiling target are required, is particularly well suited for heavy-ion experiments, because it allows the use of relatively inexpensive large-area detectors (with kinematically shaped apertures)

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*Applied Mathematics Division.

[1] R. H. Siemssen, J. V. Maher, A. Weidinger, and D. A. Bromley, Phys. Rev. Letters 19, 369 (1967).

and because of its simplicity. Thus, in principle, the use of large arrays of detectors would be feasible. For the scattering of nonidentical particles and for reactions, however, this method with a fixed array of detectors is impractical because the kinematic conditions change with angle and bombarding energy. In the present experiments this difficulty is overcome by using the Argonne 70-in. scattering chamber (which has four independent and computer-controlled arms) and by having the ASI-210 on-line computer determine and set the angles of the conjugate detectors. Thus arrays of up to sixteen 10×50-mm rectangular large-area detectors have been used, with as many as six coincident pairs of detectors. An additional important feature of the present setup is the 92 K direct-access external memory of the on-line computer, which allows up to six 64×128-channel two-dimensional coincidence spectra to be stored during a run so that the experimenter can set energy windows on the spectra of the conjugate detectors <u>after</u> the experiment has been completed.

The cases studied to date are the scattering of ^{6}Li from ^{6}Li, ^{14}N from ^{16}O,[2] and ^{16}O from ^{18}O, ^{24}Mg, ^{26}Mg, ^{28}Si, and ^{30}Si. Experiments with ^{15}N and ^{18}O as projectiles are planned.

Excitation functions for at least five angles have been obtained for ^{14}N + ^{16}O and ^{16}O + ^{18}O. Both the total masses and the products of charges in these systems are close to those for ^{16}O + ^{16}O, and therefore one expects to find similar effects for the three nuclear systems. This is borne out by experiment. Most significantly, the ^{16}O + ^{18}O excitation functions are well reproduced (Fig. 5) with virtually the same optical-model parameters as were used to describe the ^{16}O + ^{16}O scattering, except that the well radius R has been scaled with $A^{1/3}$. In contrast to the ^{16}O + ^{16}O scattering, however, the peak-to-valley ratios of the ^{16}O + ^{18}O excitation functions are

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[2] Work done in collaboration with R. Malmin and P. P. Singh, Indiana University, Bloomington, Indiana.

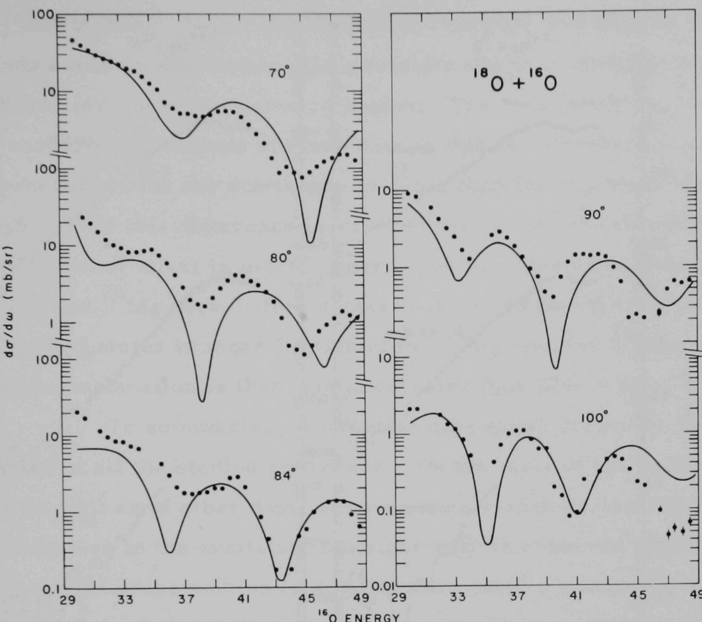

Fig. 5. Excitation functions for the elastic scattering of ^{16}O from ^{18}O at center-of-mass angles of 70°, 80°, 84°, 90°, and 100°. The solid curves are the result of optical-model calculations with the $^{16}O + ^{16}O$ parameters.

less pronounced, and the decrease in amplitude of the gross structure with increasing energy is much more similar to the optical-model predictions. From this comparison it appears that $^{16}O + ^{16}O$ behaves anomalously. The doubly-magic nucleus ^{16}O differs from ^{18}O mainly in its "stiffness," as is manifested by the high excitation energy of the lowest collective state in ^{16}O. ^{15}N has a similar structure, and therefore a study of $^{15}N + ^{16}O$ is of particular interest. Such an investigation is planned[2] for the near future.

The study of the ^{16}O scattering from ^{24}Mg, ^{26}Mg, ^{28}Si, and ^{30}Si was undertaken to search for a consistent heavy-ion—nucleus potential with parameters systematically varying as a function

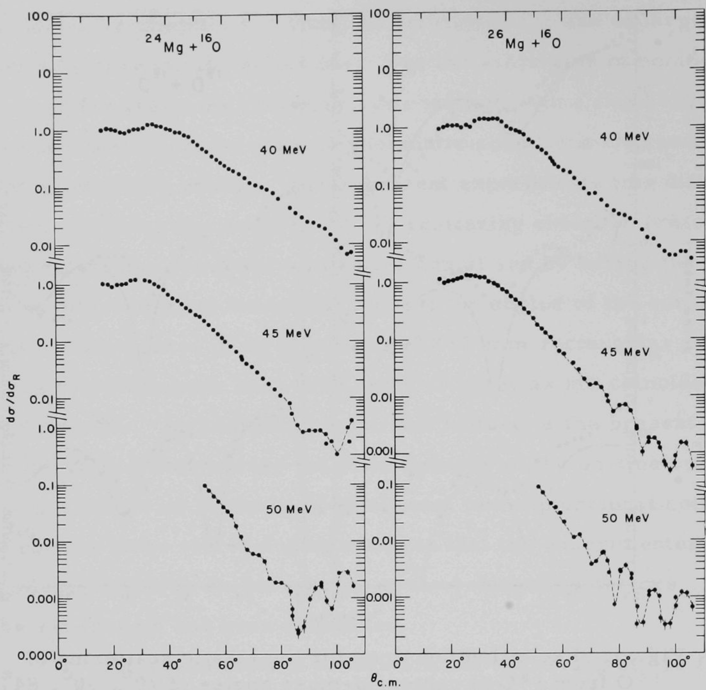

Fig. 6. Angular distributions of ^{16}O scattered off ^{24}Mg and ^{26}Mg at 40, 45, and 50 MeV incident energy.

of mass and of incident energy. For such a study one would preferably measure the scattering on the heaviest possible target nuclei, since these are the ones for which structure effects would be the least important. On the other hand, the bombarding energy has to be sufficiently above the barrier that one can hope to find diffraction structure both in the angular distributions and in the excitation functions. The Mg and Si isotopes are about the heaviest nuclei that fulfill these conditions for the energy range covered by the FN tandem.

Excitation functions in the angular range from 50° to 100° were obtained for energies from 30 to 50 MeV, and in addition angular distributions (Fig. 6) were measured for the Mg isotopes at

40, 45, and 50 MeV. Again the excitation functions and angular distributions exhibit a diffraction-like gross structure at energies above 40 MeV and for the most backward angles. The most striking, and as yet unexplained, feature of these data is that the structure is much more pronounced for the scattering by ^{26}Mg than for that by ^{24}Mg. Although part of this difference is reproduced by the optical model, the experimental effect is much larger. One possible explanation is that ^{24}Mg and ^{26}Mg have different deformations so that the coupling to the excited states is more important for ^{24}Mg than for ^{26}Mg. An alternative explanation is that elastic transfer may play a role.

To summarize, diffraction-like gross structure has been found in all the studied processes. On the basis of the present results as well as of other data, it now seems rather certain that gross structure in the excitation functions will be observed whenever the differential cross section is smaller than about a hundredth to a thousandth of the Rutherford scattering cross section. The present data, however, also point to an intrinsic dilemma of heavy-ion scattering studies. Cross sections usually are extremely small (10—100 μb) when there is pronounced gross structure—the phenomenon to which the theoretical analysis is most sensitive. The smallness of these cross sections poses not only an extreme experimental problem, but in addition one would expect that competing processes (such as compound elastic scattering and elastic transfer, as well as strong-coupling effects) would no longer be negligible.

The gross structure is predominantly a diffraction phenomenon which is at least qualitatively described by the optical model. Although the optical-model analysis of the present data still is in a preliminary stage, it can be expected that much improved fits will be obtained in a more extensive parameter search. The energy and angle dependences of the differential cross section are as would be predicted from the ordinary optical model, and it therefore seems unlikely that deviations from the ordinary optical model (e.g., cored and ℓ-dependent potentials) will be needed to fit the data. A comparison of the $^{16}O + ^{18}O$ data with those from the $^{16}O + ^{16}O$ scattering shows that the $^{16}O + ^{16}O$ system behaves anomalously with respect to the optical model and probably also with respect to the scattering from neighboring nuclei.

MÖSSBAUER ISOMER SHIFT IN ^{243}Am

G. M. Kalvius,* S. L. Ruby, B. D. Dunlap,* G. K. Shenoy,*
D. Cohen,† and M. B. Brodsky‡

Nuclear gamma-ray resonance (the Mössbauer effect) has been observed in a number of isotopes of actinide elements such as ^{232}Th,[1] ^{231}Pa,[2] ^{237}Np,[3] and ^{238}U.[4] The series has been extended by our recent observation of the resonance of the 83.9-keV gamma ray in ^{243}Am. This transition has very favorable nuclear properties for the investigation of the Mössbauer effect. However, the rather short half-life (7.95×10^3 yr) makes it necessary to work with extremely radioactive absorbers. The decay product, ^{239}Np, shows a strong 75-keV gamma ray, along with the K x rays around 100 keV which must be separated from the 83.9-keV resonant gamma ray by the use of a Ge(Li) detector.[5]

^{243}Pu sources (half-life = 4.98 h) were produced by an (n, γ) reaction on 7 mg of isotopically pure $^{242}PuO_2$. The source strengths were about 50 mCi. The absorbers were AmO_2 and AmF_3 (about 30 mg/cm^2) which have a specific activity of about 0.2 mCi/mg. The resonance spectra are shown in Fig. 7.

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*Solid State Science Division.

†Chemistry Division.

‡Metallurgy Division.

[1] N. Hershkowitz, C. G. Jacobs, Jr., and K. A. Murphy, Phys. Letters 27, B563 (1968).

[2] W. L. Croft, J. A. Stone, and W. L. Pillinger, J. Inorg. Nucl. Chem. 30, 3203 (1968).

[3] J. A. Stone and W. L. Pillinger, Phys. Rev. Letters 13, 200 (1964).

[4] S. L. Ruby, G. M. Kalvius, B. D. Dunlap, G. K. Shenoy, D. Cohen, and M. B. Brodsky, Phys. Rev. (in press).

[5] For general considerations on using the radioactive absorbers, see A. J. F. Boyle and G. J. Perlow, Mössbauer Effect Methodology, edited by I. J. Gruverman (Plenum Press, New York, 1969), Vol. 5, in press.

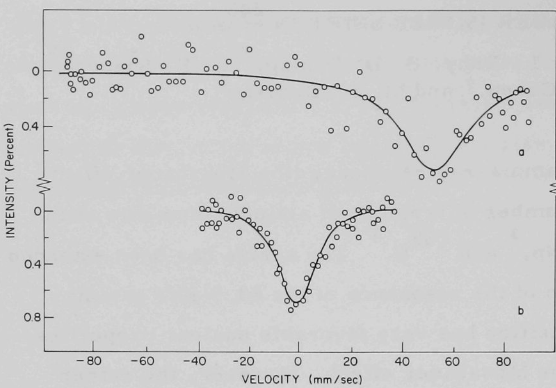

Fig. 7. Mössbauer spectra: (a) for a PuO_2 source and AmF_3 absorber, both at 4.2°K, and (b) for a PuO_2 source and AmO_2 absorber, both at 20°K.

The observed linewidths for AmO_2 varied from 22 ± 1 mm/sec to 5 ± 1 mm/sec as the source was warmed from 4.2° to 77°K. A change in absorber temperature between 4.2° and 77°K, with the source at a constant temperature of 4.2°K, did not affect the shape of the resonance spectrum. The minimum width is about three times the natural width, obtained from the lifetime reported by Friedman *et al.*[6]

The AmF_3 at 4.2°K gave a symmetrical resonance line with a width of 20 ± 1 mm/sec and was shifted by 53 ± 1 mm/sec relative to AmO_2. The observed shift is by far the largest reported per unit change in charge state. On the assumption that the electronic configurations of Am in these absorbers are $5f^6$ and $5f^5$, respectively, the relativistically corrected electron density difference ($\Delta\Psi_0{}^2 = 255\ a_0{}^{-3}$) obtained from SCF Hartree-Fock wavefunctions[7] gave $\delta\langle r^2\rangle/\langle r^2\rangle = -(9 \pm 3) \times 10^{-4}$. The magnitude and sign of this difference in nuclear radii have important implications for nuclear structure.

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[6] A. M. Friedman, I. Ahmad, J. Milsted, and D. W. Engelkemeir, Nucl. Phys. A127, 33 (1969).

[7] F. Herman and S. Skillman, Atomic Structure Calculations (Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1963).

The observation of the 83.9-keV resonance in ^{243}Am is very promising for the investigation of solid-state chemical properties of actinide compounds.

POLARIZATION OF CHANNELED PARTICLES

M. Kaminsky

As energetic ions travel through a monocrystalline solid in certain crystallographic directions, the regular arrangement of the lattice atoms can guide them through the spaces between planes (planar channeling) or along channels formed by parallel rows of atoms (axial channeling). The impact parameters of successive collisions then become correlated so that their distribution is not random as it is for ions penetrating through amorphous solids. This effect has been used to develop a method of polarizing deuterons by passing them through a monocrystalline nickel foil magnetized to saturation. A beam with tensor polarization $P_{zz} = -0.32 \pm 0.01$ is obtained. This method is expected to be a very useful technique of producing polarized projectiles for use in nuclear accelerators.

The discovery of the polarization produced by channeling is the culmination of a long series of Argonne investigations on the behavior of energetic light ions ($Z = 1$ or 2) impinging on metal monocrystals. Earlier work showed the influence of axial channeling on the yields of secondary particles, on energy loss, and on charge-transfer processes. In the present effort to polarize deuterons by channeling, the main requisite is to preferentially populate some of the six components of the hyperfine states of the deuterium atom (three for each of the two magnetic quantum numbers). The technique investigated is to direct the incident deuterons accurately in one of the channeling directions of a monocrystalline nickel foil magnetized to saturation so that in an appropriate energy range the deuterons would capture polarized electrons (e.g., from the 3d states in Ni). These electrons have only one of the two possible spin orientations, since the spin directions point preferentially along the magnetic field lines, and three of the six hyperfine states will not be populated. The resulting polarized deuterium atoms emerging from the magnetized monocrystalline foil then travel through a weak uniform magnetic field for a sufficiently long time that part of the electron polarization is transferred to the deuteron by hyperfine interaction. Here "sufficiently long" means that the transit time is much longer than the period of Larmor precession of the nuclear magnetic moment. Since the populations of the three remaining hyperfine states are different in weak magnetic fields, a polarization of the deuteron can be expected. After the beam has passed through the region of weak magnetic field, the tensor polarization of the well-channeled deuterium atoms (now polarized both in electron spin and in nuclear spin) can be determined by measuring the angular distribution of the α particles emitted in the $T(d,n)He^4$ reaction.

An essential feature of the polarization method described here is that only <u>well-channeled</u> deuterium atoms emerging from a <u>monocrystalline</u> foil are detected. In our experiments, a mass-analyzed, highly-collimated D^+ ion beam with a half angle of 0.01° was incident within 0.1° of a [110] direction in a Ni(110) foil magnetized to saturation parallel to one of the [111] axes in the plane of the nickel foil. When placed in the target holder, the foils were kept in a magnetic field (approximately 160 G) parallel to the original magnetization direction (e.g., in the case of the monocrystalline foils, parallel to one of the [111] directions in the plane of the foil).

As shown in Fig. 8, the atoms emerging from the foil were first passed through an aperture of half-angle $\sim 0.15^\circ$ at a scattering angle of $0 \pm 0.1^\circ$ with respect to the incident beam direction. They then spent $1-2 \times 10^{-7}$ sec in traversing a homogeneous magnetic field of ~ 10 G which can be directed along either the $\pm z$ or the $\pm y$ axis (i.e., either parallel or perpendicular to the direction of magnetization of the foil) by energizing one or the other of a pair of electromagnets. The charged atoms were deflected out of the beam by applying appropriate potentials to the insulated pole pieces, while the neutral atoms passed through the second collimator system (half

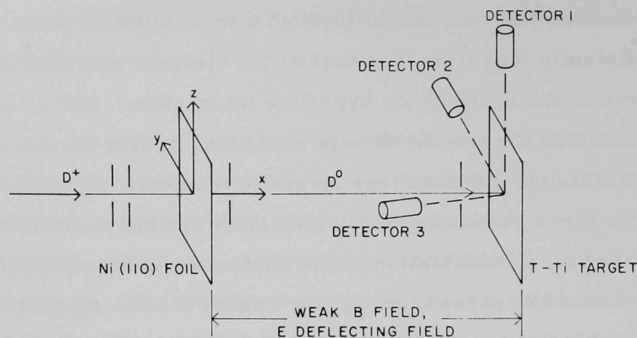

Fig. 8. Schematic diagram of experimental arrangement.

angle of acceptance $\approx 0.15^\circ$) and struck either a movable surface-barrier solid-state detector (to determine the energy spectrum in the emergent beam) or the T-Ti target (to determine the polarization).

Whenever the incident beam was parallel within 0.3° to the [110] axis in the monocrystalline Ni foil, the energy spectrum of the emergent beam (both for the total beam and for the neutral fraction) consisted of two well separated peaks; the mean energy $\overline{E}_n$ of the lower one corresponded to the normal energy loss observed for polycrystalline targets of the same material and the same thickness, while the mean energy $\overline{E}_{ch}$ of the high-energy peak reflects the reduced loss rate for channeled particles.

To avoid detection of the small residue of randomly scattered atoms, the incident-ion energy was so chosen that $\overline{E}_{ch}$ was in the range 100—130 keV and E_n was well below the threshold for the $T(d,n)He^4$ reaction, which has a peak cross section of 5 b at the $J=\frac{3}{2}^+$ resonance in He^5 at E_d = 107 keV.

For the case in which the polarization was in the ±z direction (Fig. 8), solid-state counters 1, 2, and 3 detected the α particles emitted in the c.m. directions $\phi_1 = 7^\circ$, $\phi_2 = 90^\circ$, and $\phi_3 = 90^\circ$. For an additional test, the polarization axis was reoriented by applying

TABLE I. Values for the tensor polarization P_{zz} or P_{yy} as determined for the measured ratios $R_{\mu\nu}$.

Polarization direction	Detector angles ϕ_ν ϕ_μ	$R_{\mu\nu}$	Tensor polarization
± z	ϕ_1 ϕ_2	+1.260 ± 0.010	P_{zz} = -0.32 ± 0.01
	ϕ_1 ϕ_3	+1.258 ± 0.010	P_{zz} = -0.32 ± 0.01
± y	ϕ_1 ϕ_3	+0.787 ± 0.011	P_{yy} = -0.32 ± 0.01
	ϕ_2 ϕ_3	+0.852 ± 0.010	P_{yy} = -0.32 ± 0.01

the weak magnetic field in the ±y direction. For this case, the c.m. angles were $\phi_1 = 90^{\circ}$, $\phi_2 = 82^{\circ}$, and $\phi_3 = 7^{\circ}$. The results are shown in Table I. Our observed value P_{zz} (or P_{yy}) $\approx -\frac{1}{3}$ corresponds to a fractional occupation $N_0 \approx \frac{4}{9}$; for P_{zz} (or P_{yy}) = 0 (unpolarized deuterons), i.e., for $N_0 = N_+ = N_-$, the value of N_0 would be $\sim\frac{3}{9}$.

To test Zavoiskii's proposal[1] for polarizing deuterons, we passed deuterons through polycrystalline foils magnetized to saturation and observed $P_{zz} = -0.002 \pm 0.010$ for the 1.14-μ-thick foil and $P_{zz} = +0.003 \pm 0.010$ for the 1.87-μ-thick foil. These results indicate no significant tensor polarization (i.e., $P_{zz} \approx 0$) and thus support some of the criticism[2] of his proposal.

It appears that this method of polarizing channeled particles will permit the development of a relatively inexpensive source of polarized ions.[3] With present techniques, it appears feasible to obtain 500 nA/cm^2 of channeled deuterium atoms with their nuclear spins polarized, and (by passing this beam through a second thin monocrystalline film) to obtain approximately 10—20 nA/cm^2 of

[1] E. K. Zavoiskii, Soviet Phys.—JETP 5, 378 (1957).

[2] W. Haeberli, Ann. Rev. Nucl. Sci. 17, 420 (1967); Proc. 2nd Karlsruhe Symposium on Polarization Phenomena (Birkhauser Verlag, Basel, 1966), pp. 69-70.

[3] M. Kaminsky, U. S. Patent applied for.

negative polarized ions. These intensities can probably be increased significantly by cooling the films, by somewhat relaxing the present requirements of strong collimation of the emergent beam (without a significant decrease in beam polarization), and by using films whose thicknesses are optimal for the deuteron velocity ranges used.

This method of polarizing channeled particles is expected to work well not only for deuterons passing through monocrystalline nickel foils but also for other particles (e.g., protons, tritons, He^3) and for monocrystalline foils of other ferromagnetic and paramagnetic materials (e.g., Gd, Tb, Dy, Ho).

II. REPORTS AT MEETINGS

The abstracts and summaries that follow are not necessarily identical to those submitted for the meeting. In some cases, the authors have corrected or expanded abstracts; and summaries of contributed papers commonly have been shortened.

American Physical Society

Washington, D. C., 28 April—1 May 1969

DIRECT REACTIONS ON Be^{10}

D. L. Auton, B. Zeidman, H. T. Fortune, J. P. Schiffer, and R. C. Bearse

Bull. Am. Phys. Soc. 14, 489 (April 1969)

A Be^{10} target has been prepared from beryllium enriched by the AREMIS isotope separator. Angular distributions from the (d,p), (d,t), (p,p'), and (d,d) reactions on Be^{10} were obtained with this target. Protons leading to the ground state and first excited state of Be^{11} at 12.0-MeV incident energy indicate spin and parity assignments of $\frac{1}{2}^+$ and $\frac{1}{2}^-$, respectively. At an incident deuteron energy of 15.0 MeV, tritons could be detected up to an excitation of 5.5 MeV in Be^9. No evidence was seen for an ℓ=1 transition to known states at less than 3.0-MeV excitation in Be^9, other than that to the ground state. Spectroscopic factors for observed states in the (d,p) and (d,t) reactions were extracted with the code JULIE. Elastic and inelastic scattering of protons was observed on Be^{10} at several energies from 12.0 to 16.0 MeV. The elastic scattering was compared with optical-model calculations, and values of B(E2) for the 3.37-MeV $(2^+) \rightarrow 0.0\ (0^+)$ transition were obtained with the code JULIE. Results of these experiments will be compared with applicable nuclear models.

STATES OF Ho^{166} FROM AVERAGE RESONANCE CAPTURE IN $Ho^{165}(n,\gamma)Ho^{166}$

L. M. Bollinger and G. E. Thomas

Bull. Am. Phys. Soc. 14, 514-515 (April 1969)

The internal-target facility at the reactor CP-5 was used to measure the γ-ray spectrum formed by average resonance capture[1] of neutrons in Ho^{166}. The high-energy transitions observed give directly the energies E of 52 low-energy states in Ho^{166}, and their intensities give the parities π and set limits on spins J. The observed states (listed in the form EJ^{π}, with $i \equiv 3$ or 4, $j \equiv 2$ or 5, $k \equiv 1$ or 6, and $n \equiv 2$, 3, 4, or 5) are 54 j^-, 82 k^-, 171 i^-, 180 i^-, 191 i^+, 261 i^+, 264 j^+, 277 k^-, 295 k^-, 330 j^-, 348 j^+, 372 i^+, 417 j^-, 430 j^+, 454 k^-, 464 j^+, 471 j^+, 475 n^-, 482 i^+, 522 i^+, 543 n^-, 548 i^+, 559 i^+, 562 n^-, 592 i^+, 598 i^+, 605 j^+, 628 n^-, 634 n^+, 638 n^-, 655 n^+, 662 n^+, 667 n^-, 672 n^+, 683 n^-, 694 n^+, 704 n^-, 719 i^+, 726 n^-, 736 i^+, 741 n^-, 757 n^-, 760 n^-, 769 j^+, 771 n^-, 789 n^-, 792 n^-, 806 j^+, 814 i^+, 824 n^-, 831 n^+, and 836 n^+; uncertainties in energies are <1 keV. These data support the rotational-band structure reported previously[2] and give evidence for several additional bands.

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[1] L. M. Bollinger and G. E. Thomas, Phys. Rev. Letters 21, 233 (1968).

[2] H. T. Motz et al., Phys. Rev. 155, 1265 (1967).

ACCURATE METHOD OF DETERMINING COUNTING LOSSES IN NUCLEAR RADIATION DETECTION SYSTEMS

H. H. Bolotin, M. G. Strauss,* and D. A. McClure

Bull. Am. Phys. Soc. 14, 532 (April 1969)

Paralysis in pulse-selection circuits (pileup rejectors, etc.) of high-resolution pulse spectrometers can cause counting losses that are not negligible compared with those due to the ADC and

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memory of fast multichannel analyzers. A method has been developed to determine accurately the counting losses of the complete pulse-processing system. This method, valid for either variable or constant counting rates, is based on a technique in which the rate of radiation incident upon the detector is sampled continuously. At the expiration of every sampling interval, a pulser signal is injected into the preamplifier. At the end of the experiment, the total number of injected pulses is compared with the number of injected pulses that are recorded in the multichannel analyzer. This comparison allows an accurate determination of the counting losses due to all effects during the course of the experiment. Applications of this technique to fluctuating and nonreproducible counting rates encountered in charged-particle-induced reactions and in radioactive-decay studies will be considered, and the method will be described and evaluated in detail.

PRIMARY GAMMA RAYS IN ^{148}Sm AND ^{150}Sm FOLLOWING AVERAGE NEUTRON RESONANCE CAPTURE

D. J. Buss and R. K. Smither

Bull. Am. Phys. Soc. 14, 514 (April 1969)

The spectrum of high-energy γ rays emitted from the ^{147}Sm(n, γ)^{148}Sm and ^{149}Sm(n, γ)^{150}Sm reactions were studied by use of the recently developed average-resonance-capture technique. The measurements were taken with a boron-shielded Sm sample placed in the through-hole facility at the Argonne research reactor CP-5. The primary γ-ray intensities separate into distinct groups as can be seen in Fig. 9. These groups, which are characterized by the spins and parities of the final states, i.e., (3^+, 4^+), (2^+, 5^+), (3^-, 4^-), etc., make it possible to assign a parity and a choice of spins to a great many of the levels in the level scheme. When this

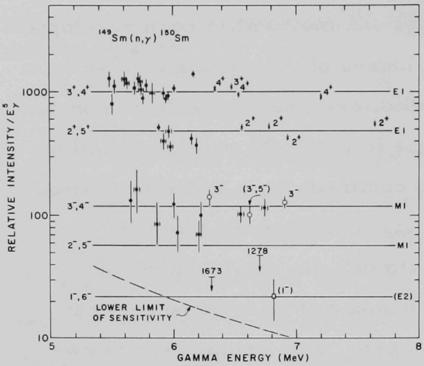

Fig. 9. Plot of normalized relative gamma-ray intensities for primary transitions in the $^{149}Sm(n,\gamma)^{150}Sm$ reaction following average resonance capture. The crosses indicate known E1 transitions whose J^{π} is indicated by the labels on the plot. The open squares and circles represent transitions to known negative-parity states. The plotted intensity is proportional to $I_{\gamma} \times (E_0{}^5/E_{\gamma}{}^5)$.

work is combined with previously published work, spin and parity assignments can be made for 25 states in ^{148}Sm and for 40 states in ^{150}Sm.

HIGHLY EXCITED STATES IN C^{12}, N^{14}, AND O^{16} FROM Li-INDUCED REACTIONS ON B^{10} AND C^{12}

J. R. Comfort, H. T. Fortune, G. C. Morrison, and B. Zeidman
Bull. Am. Phys. Soc. 14, 507 (April 1969)

A similar report, presented at Heidelberg, appears on p. 49.

STUDY OF (α,t) REACTIONS ON 1p-SHELL NUCLEI

H. T. Fortune, D. Dehnhard, R. H. Siemssen, and B. Zeidman
Bull. Am. Phys. Soc. 14, 487 (April 1969)

The (α,t) reaction on targets of ^6Li, ^{10}B, ^{11}B, ^{12}C, and ^{13}C have been studied at an incident α energy of 46 MeV. Angular distributions have been obtained over the approximate angular range $\theta_{c.m.} = 9^{\circ}-75^{\circ}$ for the transitions to the ground state and to excited states at 0.431 and 4.53 MeV in ^7Be; to states up to 8.10 MeV in ^{11}C;

to states at 4.433, 7.66, 9.63, and 12.70 MeV in ^{12}C; to the doublet at 3.55 MeV in ^{13}N; and to states up to 6 MeV in ^{14}N. The data are consistent with the assumption of a direct interaction in which a proton is transferred from the incident α particle. To date, DWBA calculations have reproduced the experimental angular distributions over only a limited angular range.

DELBRÜCK EFFECT IN ELASTIC SCATTERING OF 10.8-MeV GAMMA RAYS

H. E. Jackson and K. J. Wetzel

Bull. Am. Phys. Soc. 14, 607 (April 1969)

In an experiment performed at the Argonne CP-5 reactor, we have measured the differential elastic-scattering cross section for 10.83-MeV photons at laboratory angles of 20°, 30°, 60°, 90°, and 150°. An external photon beam was produced by the reaction $^{14}N(n, \gamma)^{15}N$. Radiation scattered by targets of Pb and U was observed in a Ge(Li) detector with a resolution width of approximately 15 keV at 10.8 MeV. For scattering angles less than 45° the process is dominated by the Delbrück effect. For all experimental scattering angles, good agreement exists between the measured cross section and that predicted by recently calculated Delbrück scattering amplitudes when contributions from nuclear resonance and nuclear Thomson scattering are included.

THE MÖSSBAUER EFFECT IN Am^{243}

G. M. Kalvius,* S. L. Ruby, B. D. Dunlap,* G. K. Shenoy,*
D. Cohen,† and M. B. Brodsky‡

Bull. Am. Phys. Soc. 14, 521 (April 1969)

In the actinide elements, high-resolution Mössbauer spectroscopy has so far been demonstrated only in Np^{237}. (Less sharp, but still useful, nuclear gamma-ray resonance (NGR) work has been done in Th, Pa, and U.) Am^{243} is very similar to Np^{237} so far as decay schemes, gamma-ray emission, and nuclear structure are concerned. We report here the first examination of its utility as a Mössbauer nucleus.

Some modification of the usual techniques had to be made to accommodate the strong radioactivity of the absorber. The source is some 5 mg of $Pu^{242}O_2$ which is irradiated for 1 h in a neutron flux of 2×10^{13} cm^{-2} sec^{-1}. This provides so large a flux of the 83.9-keV Am^{243} gamma rays that the 75-keV gamma rays emitted by the Np^{239} (after α decay from Am^{243}) do not dominate the spectrum. Using a Ge(Li) detector, we were able to get good-quality spectra during some 4 h after irradiation ($T_{1/2}$ = 5 h for Pu^{243}). Since the counting rates are high, this is long enough for adequate counting statistics.

So far, we have examined two absorbers, AmO_2 and AmF_3. A very large isomer shift (52 mm/sec) is observed. Although the lifetime of the PuO_2 source implies a minimum linewidth of 2.1 mm/sec, the observed width at 77°K is 5.5 mm/sec and at 4°K the width is broadened to 25 mm/sec. This broadening is not yet understood. A source that does not behave in this way would improve the experiments technically.

When CP-5 is put back in use, these experiments will be extended.

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†Chemistry Division.

‡Metallurgy Division.

A STUDY OF THE WEAK INTERACTION BY MEANS OF THE DECAY OF POLARIZED NEUTRONS

V. E. Krohn

Invited paper listed by title only: Bull. Am. Phys. Soc. 14, 565 (April 1969)

A full report on this work has been submitted for publication in the Physical Review.

LIFETIME OF THE 11-keV LEVEL IN Cs^{134m}

F. J. Lynch and L. E. Glendenin*

Bull. Am. Phys. Soc. 14, 629 (April 1969)

The mean life of the 11-keV level following the decay of Cs^{134m} has been measured by a delayed-coincidence technique and found to be 69 ± 1 nsec. An indirect measurement of the total internal-conversion coefficient for this transition ($\alpha = 105$) agrees closely with the theoretical value for a pure M1 transition. This implies that the mean life for radiative decay is $\tau_0 = 7155$ nsec. This is about 1.8 times the radiative mean life calculated with the odd-group model with the aid of the magnetic moments of neighboring nuclei.

*Chemistry Division.

STUDY OF THE (He^3,d) REACTION FOR $A \approx 31$

Richard A. Morrison

Bull. Am. Phys. Soc. 14, 567 (April 1969)

The (He^3,d) reaction on targets of Si^{30}, P^{31}, and S^{32} has been produced by 15-MeV He^3 particles—and on S^{34} targets by 13-MeV He^3. Angular distributions were measured at $\sim 3^o$ intervals from 7^o to 45^o and at $\sim 5^o$ intervals from 45^o to $\sim 90^o$, and absolute cross sections were deduced. The data on P^{31} and Si^{30} at $E(He^3) = 15$

MeV were used to test He^3 optical models; deuteron optical models were tested against available data. Levels were analyzed to 5.25-MeV excitation in P^{31}, 6.62 MeV in S^{32}, 2.85 MeV in Cl^{33}, and 5.76 MeV in Cl^{35} by use of the DWBA code JULIE; ℓ-value assignments and spectroscopic factors were obtained.

COULOMB ENERGIES AND NUCLEAR RADII

J. A. Nolen, Jr.,* and J. P. Schiffer

Bull. Am. Phys. Soc. 14, 584 (April 1969)

A similar report, presented at Montreal, appears on p. 79.

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*University of Maryland, College Park, Maryland.

SEARCH FOR PARITY VIOLATION IN THE DECAY OF THE 8.88-MeV STATE IN O^{16}

R. Segel

Invited paper listed by title only: Bull. Am. Phys. Soc. 14, 565 (April 1969)

O^{16} ELASTIC SCATTERING FROM $Mg^{24,26}$ AND $Si^{28,30}$

R. H. Siemssen, H. T. Fortune, J. L. Yntema, and A. Richter

Bull. Am. Phys. Soc. 14, 548-549 (April 1969)

The content of this paper is included in the more comprehensive report on p. 15.

AVERAGE RESONANCE CAPTURE IN ^{113}Cd

R. K. Smither, D. J. Buss, L. M. Bollinger, and G. E. Thomas

Bull. Am. Phys. Soc. 14, 513 (April 1969)

A sample of Cd was surrounded with boron and placed in the high-flux region of the Argonne research reactor. The resultant neutron-capture γ-ray spectrum was investigated with a Ge(Li) detector. The primary transitions to 30 levels in ^{114}Cd below 3 MeV excitation were identified on the basis of their energy. The normalized intensities I_γ/E_γ^3 were compared with the spin and parity of the levels, assigned on the basis of previous (n, γ) and (d, p) experiments, and were found to fall in groups corresponding to J^π assignments of 0^+, 1^+, 2^+, 1^-, and 2^-. The data are plotted in Fig. 10. This separation makes it possible to suggest spin and parity assignments for 30 levels in ^{114}Cd.

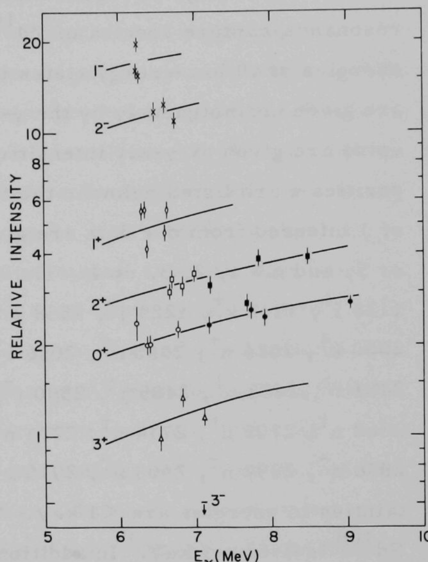

Fig. 10. Plot of normalized gamma intensities of the primary transitions resulting from average resonance capture in the ^{113}Cd(n, γ)^{114}Cd reaction. The relative intensity is proportional to $I_\gamma \times (E_0/E_\gamma)^3$. The filled circles and squares indicate transitions to known 0^+ and 2^+ states, respectively.

STATES OF Pd^{106} FROM AVERAGE RESONANCE CAPTURE IN $Pd^{105}(n,\gamma)Pd^{106}$

G. E. Thomas and L. M. Bollinger

Bull. Am. Phys. Soc. 14, 515 (April 1969)

High-energy transitions observed in the average resonance-capture spectra of $Pd^{105}(n,\gamma)Pd^{106}$ give directly the energies of 40 low-energy states in Pd^{106}. Parities of these states are given unambiguously by the γ-ray line shapes, and limits for the spins are given by γ-ray intensities. The energies E, spins J, and parities π are listed below in the form EJ^{π}, where the possible values of J inferred from our data are given by $i \equiv 2$ or 3, $j \equiv 1$ or 4, $k \equiv 0$ or 5, and $n \equiv 1$, 2, 3, or 4. The observed states are 0 k^+, 512 n^+, 1128 i^+, 1113 k^+, 1229 j^+, 1558 j^+, 1562 i^+, 1705 k^+, 1910 n^+, 1933 n^+, 2000 k^+, 2055 n^+, 2080 n^+, 2086 i^-, 2243 n^+, 2283 n^+, 2307 j^-, 2351 n^+, 2401 i^-, 2438 n^+, 2485 j^-, 2500 i^-, 2579 n^-, 2590 n^+, 2628 n^+, 2650 n^+, 2662 n^+, 2705 n^+, 2714 n^+, 2776 n^+, 2784 n^+, 2848 n^+, 2861 j^-, 2878 n^+, 2886 n^-, 2899 n^-, 2908 n^-, 2916 n^+, 2936 n^-, and 2973 n^-. Uncertainties in energies are <1 keV. The neutron separation energy of Pd^{106} is 9562 ± 1 keV. In addition to the spectroscopic data, the average resonance-capture measurements provide reliable average values for the relative widths of E1, M1, and E2 high-energy transitions in Pd^{106}.

COMPUTER-CONTROLLED MULTIPLE-DETECTOR SYSTEM FOR HEAVY-ION SCATTERING EXPERIMENTS

J. W. Tippie,* J. Bicek, H. T. Fortune, R. H. Siemssen, and J. L. Yntema

Bull. Am. Phys. Soc. 14, 533 (April 1969)

The content of this paper is included in the more comprehensive report on p. 15.

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*Applied Mathematics Division.

METHOD FOR DWBA CALCULATION OF STRIPPING TO UNBOUND STATES

C. M. Vincent and H. T. Fortune

Bull. Am. Phys. Soc. 14, 572 (April 1969)

The Huby-Mines technique for calculating the pathological radial integrals in the distorted-wave theory of stripping to unbound states requires a large number of points and converges slowly. A contour integration technique has been devised to overcome these difficulties. The usual integrand, which oscillates for unbound states, is replaced by a smooth integrand which tends exponentially to 0 at infinity. No "convergence factor" is used. The method is also advantageous for very weakly bound final states. Calculations have been performed for $^{16}O(d,p)^{17}O$ to the 5.08-MeV resonant state, for which case the results of the Huby-Mines method are available.[1]

The shape of the proton angular distribution was found to vary little over the width of the neutron resonance. Since the internal region makes only a small contribution, the cross section is determined almost entirely by the phase shift of the neutron wave function. It follows that the magnitude of the $^{16}O(d,p)$ cross section measures the <u>width</u> of the narrow $^{16}O + n$ resonance.

Our analysis of the $^{16}O(d,p)$ data of Alty *et al.* implies a width of about 60 keV, which is to be compared with the value 85 ± 5 keV deduced from $^{16}O + n$ experiments. Corrections for the effects of finite range and nonlocality were found to increase the theoretical cross section by about 30% at 0°. In agreement with the results of Alty *et al.*[1] both deep and shallow deuteron potentials gave very similar angular distributions after application of the corrections.

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[1] J. L. Alty, L. L. Green, R. Huby, G. D. Jones, J. R. Mines, and J. F. Sharpey-Schafer, Nucl. Phys. A97, 541 (1967).

METHOD FOR DETERMINING SPINS OF NEUTRON RESONANCES

K. J. Wetzel, G. E. Thomas, L. M. Bollinger, and H. E. Jackson

Bull. Am. Phys. Soc. 14, 513 (April 1969)

The low-energy γ-ray spectra of several nuclei formed by resonant neutron capture in even-odd targets (^{105}Pd, ^{135}Ba, ^{167}Er, ^{177}Hf, ^{179}Hf, and ^{183}W) have been measured with a Ge(Li) spectrometer used with the chopper facility and time-of-flight analyzer. In many cases the relative population of low-lying 2^+, 4^+, and 6^+ levels can be directly correlated with the known resonance spin. Results are in good agreement with predictions based on the assumption that only dipole transitions occur in the cascade. Spins of several resonances in ^{187}Os and ^{189}Os have been assigned. We have attempted to assign spins to neutron resonances in ^{235}U and to extend this method to p-wave resonances in ^{91}Zr.

ANGULAR DISTRIBUTIONS OF HEAVY IONS PRODUCED BY ^{3}He BOMBARDMENT OF ^{12}C

B. Zeidman and H. T. Fortune

Bull. Am. Phys. Soc. 14, 507 (April 1969)

A similar report, presented at Heidelberg, appears on p. 52.

International Conference on Hypernuclear Physics

Argonne National Laboratory, Argonne, Illinois, 5—7 May 1969

Λ-PARTICLE BINDING IN NUCLEAR MATTER

A. R. Bodmer and D. M. Rote*

Proceedings, Vol. II, pp. 521-597

This is a rather detailed survey of a comprehensive investigation of the binding energy of a Λ particle in nuclear matter (the Λ well depth D). Chapter 1 gives a critical discussion of the two principal procedures for obtaining the phenomenological Λ well depth D from the experimental separation energies B_Λ. A value $D \approx 30 \pm 2$ MeV, with an upper limit $D \lesssim 35$ MeV, is consistent with the results obtained from both procedures. Previous calculations are also briefly reviewed in Chap. 1.

Chapter 2 discusses the perturbation-theory results for D for purely central ΛN potentials without a repulsive core. The second-order contributions turn out to be mostly relatively small.

Chapter 3 gives the Brueckner-Bethe reaction-matrix formalism for a Λ in nuclear matter. To calculate the ΛN reaction or the g matrix, the reference-spectrum method is used in the Kallio-Day form. Higher-order g-matrix contributions are briefly discussed. The results for D in the "leading term" (g-matrix) approximation are discussed for central ΛN potentials. For these, D is sensitive predominantly to two properties of the potential, namely the short-range repulsion and the p-state interaction. Thus, firstly, the s-state contribution D_s to the well depth decreases strongly as the hard-core radius increases. Secondly, the p-state contribution D_p can be quite large and equal to about 20 MeV for a p-state interaction equal to the s-state one. One concludes that central forces consistent with the Λp scattering data could give agreement with the

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phenomenological well depth if there is a strong short-range repulsion corresponding to a rather large hard core with a radius of about 0.6 F and if also the p-state interaction is very weak and close to zero.

In Chap. 4, the effect on D of ΛN tensor forces and of the coupling of the ΛN to the ΣN channel is discussed with use of perturbation theory and of the reaction-matrix approach. We also discuss the use of effective nonlocal central potentials for scattering and for a Λ in nuclear matter. The use of these potentials can be regarded as an approximation to the complete reaction-matrix treatment and they are very useful for an understanding of the effect of tensor forces. For the ΛN interaction the tensor forces are in fact expected to be of quite short range since they are due to the exchange of K, η, and heavier mesons. The effect of such short-range tensor forces turns out to be only slightly modified in nuclear matter.

We conclude that if central and short-range tensor forces are chosen to compensate each other for low-energy scattering, then they will also quite closely compensate each other for nuclear matter. In particular, for "realistic" meson-theory (one-boson-exchange) potentials, the reduction in D as a result of suppression of the corresponding tensor forces is quite small—less than about 3 MeV. The coupling of the ΛN to the ΣN channel is quite possibly very important, in particular through the strong and long-range one-pion-exchange coupling potential which has predominantly a tensor character. The qualitative considerations concerning the effect of the nuclear medium on these couplings are quite similar to those discussed for tensor forces except that one must now allow for the $\Sigma\Lambda$ mass difference. Our reaction-matrix calculations indicate that one could readily obtain an appreciable suppression of the ΛN-ΣN coupling in nuclear matter—corresponding to reducing the well depth by as much as 10—15 MeV. If one accepts suppression of this order of magnitude, then one can tolerate a smaller hard-core radius and a weakened but still appreciable p-state interaction.

20th Mid-America Symposium on Spectroscopy

Chicago, Illinois, 12—16 May 1969

THE EFFECT OF CHANNELING ON THE CHARGE-CHANGING COLLISIONS OF ENERGETIC $^3He^+$ IONS PENETRATING THROUGH Au(100) MONOCRYSTALS

M. Kaminsky

The He ions emerging from monocrystalline or polycrystalline foils of various thicknesses were magnetically analyzed according to charge, and the ratio R(emergent beam) = $^3He^{++}/^3He^+$ was measured under ultrahigh vacuum for 0.6—2.0-MeV incident ions. For polycrystalline targets, R varied from 0.8 to 38 as E_{av}(emergent beam) increased from 0.3 to 1.0 MeV. The energy spectrum of the beam emerging from the monocrystalline foil consisted of two well-separated peaks, as observed earlier[1] for Cu(100) foils. For the low-energy peak, the R values normalized to equal emergent energy were close to those for polycrystalline foils; for the high-energy peak, which is due to channeled ions, R was significantly lower. The results suggest a lower stripping probability for ions traversing and escaping from regions of lower electron density.

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[1] M. Kaminsky, Bull. Am. Phys. Soc. 13, 1405 (1968).

Seventeenth Annual Conference on Mass Spectrometry and Allied Topics

Dallas, Texas, 18—23 May 1969

PHOTOIONIZATION OF CESIUM HALIDES: CHEMICAL SHIFT OF AUTOIONIZATION

J. Berkowitz

Several autoionization peaks have been observed in the photoionization efficiency curves of the cesium halides, somewhat displaced in energy from their positions in atomic cesium. In particular, the $(5p)^6\ 6s \rightarrow (5p)^5\ (6s)^2$ transition, which occurs at 12.306 eV in atomic cesium, is shifted to 12.1, 12.4, 12.5, and 12.6 eV for CsF, CsCl, CsBr, and CsI, respectively. These peaks are also present in the ionization efficiency curves of the dimer ions.

Siegbahn and collaborators[1] have proposed a modified free-ion model to predict the effect caused by various ligands on the binding energy of core electrons. This energy shift has the simple form

$$\Delta E = \left(\frac{1}{r} - \frac{1}{R}\right) q,$$

where (in this case) R is the internuclear distance of CsX, r is the radius of a 6s orbital in Cs, and q is one electron charge.

It is suggestive that the magnitude of the shifts observed, as well as the change of sign between CsF and the heavier cesium halides, is predicted by this equation. It should be borne in mind, however, that the equation purports to predict a change in one state whereas the autoionization peaks reflect a relative change in binding energy between the ground state and first excited state.

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[1] K. Siegbahn, C. Nordling, A. Fahlman, R. Nordberg, K. Hamrin, J. Hedman, G. Johansson, T. Bergmark, S.-E. Karlsson, I. Lindgren, and B. Lindberg, Electron Spectroscopy for Chemical Analysis; Atomic, Molecular and Solid State Structure Studied by Means of Electron Spectroscopy (Almqvist and Wiksells Publishing Co., Stockholm, 1967).

REACTIONS OF H_2^+ IN SELECTED VIBRATIONAL STATES WITH He

W. A. Chupka, J. Berkowitz, and M. E. Russell

The H_2^+ ion was formed in known vibrational states by photoionization and the microscopic cross sections were determined as a function of vibrational quantum number from 0 to 5 and of kinetic energy from thermal energies to ca. 7.0 eV in the center-of-mass system for the reactions

$$H_2^+ + He \rightarrow HeH^+ + H,$$

$$H_2^+ + He \rightarrow H^+ + H + He.$$

Both reactions are endoergic for v = 0, and the cross sections at all kinetic energies investigated show strong dependence on the vibrational state of the reactant ion. By comparison of reaction probability of collision pairs having the same total internal energy in the center-of-mass system, vibrational energy is seen to be very much more effective in causing reaction than kinetic energy.

American Physical Society

Rochester, New York, 18—20 June 1969

SHELL MODEL WITH A REALISTIC POTENTIAL

R. D. Lawson

Invited paper listed by title only: Bull. Am. Phys. Soc. 14, 726 (June 1969)

If $H_0(1) + H_0(2)$ is the single-particle Hamiltonian of two particles moving outside an inert core and V is the residual two-body interaction, the solution ψ of the two-particle eigenvalue problem must have the property that it is orthogonal to all core-occupied states. Thus the bound-state problem is described by an integro-differential equation

$$[H_0(1) + H_0(2) + V - E]\psi = \sum_m \phi_m \int \phi_m^* V\psi \, d\tau_1 \, d\tau_2 ,$$

where the sum over m goes over all Pauli-excluded states.[1] If one assumes an harmonic oscillator for the shell-model potential, the problem can be solved in the LS-coupling limit and thereafter the one-body spin-orbit force can be diagonalized.

For the A=6 system, if one truncates the Pauli principle so that states above the (1s, 0d) shell are neglected in the sum over m, the solution ψ for the $^{31}S_0$ state can be written as $\psi = \mathcal{R}_{00}(R)u_{10}(r) + \mathcal{R}_{10}(R)u_{00}(r)$, where the u's satisfy

$$\left(\frac{p^2}{m} + \tfrac{1}{4} m\omega^2 r^2 + \tfrac{3}{2}\hbar\omega - E\right) u_{10}(r) = R_{00}(r) \int \phi_1^* V \psi \, d\vec{r} \, d\vec{R} + \frac{1}{\sqrt{2}} R_{10}(r) \int \phi_2^* V \psi \, d\vec{r} \, d\vec{R},$$

$$\left(\frac{p^2}{m} + \tfrac{1}{4} m\omega^2 r^2 + \tfrac{7}{2}\hbar\omega - E\right) u_{00}(r) = \frac{1}{\sqrt{2}} R_{00}(r) \int \phi_2^* V \psi \, d\vec{r} \, d\vec{R},$$

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[1] R. D. Lawson and J. M. Soper, Nucl. Phys. A133(2), 473-480 (1969).

TABLE II. Properties of ^{6}Li.

	Experiment	Theory
Magnetic moment of ground state	0.822 nm	0.817 nm
ft for β decay $^6He \rightarrow {}^6Li$	831 ± 40 sec	848 sec
Quadrupole moment of ground state	-0.8 ± 0.08 mb	-4.66 mb
Γ_γ for 2.148-MeV E2 $3^+ \rightarrow 1^+$, $\Delta T = 0$	3×10^{-5} — 4×10^{-4} eV	8.42×10^{-5} eV
Γ_γ for 3.562-MeV M1 $0^+ \rightarrow 1^+$, $\Delta T = 1$	4.7—9 eV	6.48 eV

and $\mathcal{R}_{n\ell}(R)$ and $R_{n\ell}(r)$ are the harmonic-oscillator wave functions of the center-of-mass and relative motion, ϕ_1 is the wave function $(0s)^2_{L=0}$, and $\phi_2 = (0s, 1s)_{L=0}$. In order to take account of the three-body cluster terms, the single-particle oscillator states within the Fermi sea should be lowered. The 0s, 0p, and (1s, 0d) levels were lowered by 20 MeV. The solutions of this problem give the energy eigenvalues, and the eigenfunctions contain all possible correlations due to excitation of the two valence nucleons. When V is the Hamada-Johnston potential, $\hbar\omega = 13$ MeV, and the one-body spin-orbit force is chosen to give 3 MeV for the $p_{3/2} - p_{1/2}$ splitting in ^{5}He, the predicted spectrum of ^{6}Li is in reasonable agreement with experiment. In Table II the predictions based on these correlated wave functions are given for various multipole operators. The form factor for elastic scattering of electrons, as calculated by use of these wave functions, is close to experiment even when the oscillator constant for the 0s and 0p levels is chosen the same.

International Conference on Nuclear Reactions Induced by Heavy Ions

Heidelberg, Germany, 15—18 July 1969

Li-INDUCED REACTIONS ON ^{12}C

J. R. Comfort, H. T. Fortune, G. C. Morrison, and B. Zeidman

Previous Li-induced reactions on ^{12}C have been studied[1] at energies of about 20 MeV, where competing reaction mechanisms introduced ambiguities in the interpretation of the results. Such studies did reveal[1] that the (^{6}Li,d) and (^{7}Li,t) reactions might be favorable tools for inspecting the α-cluster rotational structure of ^{16}O. However, the low energy precluded investigation of very highly excited states which may have such 4p-4h character.

In order to extend the investigation of Li-induced reactions to higher excitation energies and to achieve a more dominant direct-reaction component, 29.0-MeV ^{6}Li and 31.5-MeV ^{7}Li beams have been obtained from the Argonne FN tandem accelerator. These bombarded a ^{12}C target about 60 $\mu g/cm^2$ thick. Reaction products were detected with an E-ΔE telescope and conventional particle-identification electronics. The resolution width achieved was about 150—200 keV. Spectra were obtained at four angles with the ^{6}Li and six angles with the ^{7}Li beam. A summary of the principal results follows.

$^{12}C(^{6}Li,\alpha)^{14}N$. Levels could be clearly identified to an excitation energy exceeding 13 MeV. The energies are consistent with previous studies.[2,3] The relative population intensities of the

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[1] K. Meier-Ewert, K. Bethge, and K.-O. Pfeiffer, Nucl. Phys. A110, 142 (1968).

[2] R. H. Pehl, E. Rivet, J. Cerney, and B. G. Harvey, Phys. Rev. 137, B114 (1965).

[3] N. F. Mangelson, B. G. Harvey, and N. K. Glendenning, Nucl. Phys. A117, 161 (1968).

levels are similar to those of the (α, d) reaction,[2] except that the 8.97-MeV level ($J^{\pi} = 5^{+}$) does not appear to be as strongly populated. The cross section of the first T=1 level at 2.311 MeV has a limit of $\leq 10\ \mu b/sr$.

<u>$^{12}C(^{7}Li,\alpha)^{15}N$.</u> The remarkable feature of this reaction is the population of sharp levels (narrower than the resolution width) up to excitation energies exceeding 22 MeV. The "levels" are clearly distinct, but each may contain several unresolved components.

<u>$^{12}C(^{6}Li,d)^{16}O$ and $^{12}C(^{7}Li,t)^{16}O$.</u> Spectra from these reactions, spanning the excitation region between 11 and 22 MeV, are shown in Fig. 11. The most prominent states are the group between 14 and 15 MeV, and the $J^{\pi} = 6^{+}$ state at 16.2 MeV (Q = -10.5 and -11.5 MeV, respectively). The $J^{\pi} = 4^{+}$ state at 10.36 MeV is also seen at 30° in the $(^{7}Li,t)$ spectrum.

We report the existence of a new level at about 20.7 MeV in ^{16}O. Although it is definitely present in the $(^{7}Li,t)$ spectra (Q = -16 MeV), it is more clearly discernible in the $(^{6}Li,d)$ spectra (Q = -15 MeV).

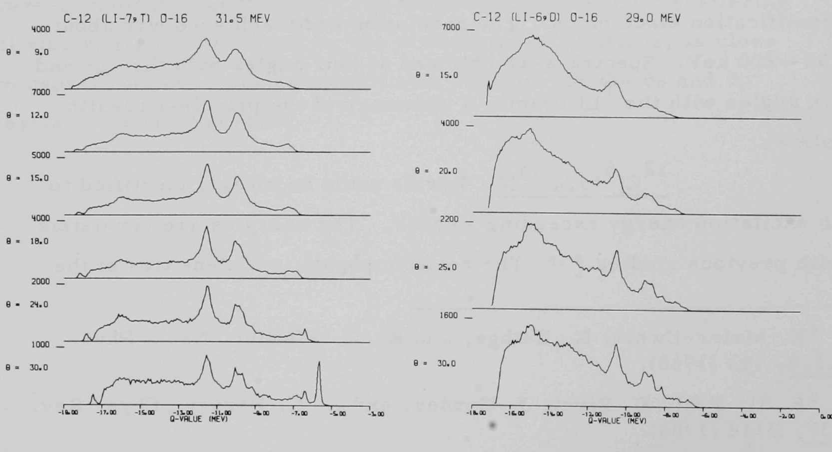

Fig. 11. Spectra for $(^{7}Li,t)$ and $(^{6}Li,d)$ reactions on ^{12}C. Angles and vertical scales are indicated. Ground-state Q values are 4.69 and 5.69 MeV, respectively.

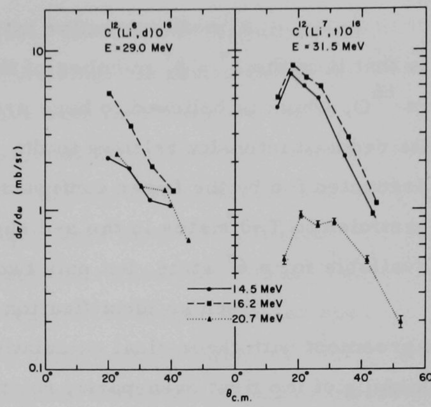

Fig. 12. Angular distributions for the (^{6}Li,d) and (^{7}Li,t) reactions on ^{12}C to three excited states in ^{16}O.

The break-up and continuum backgrounds have been estimated and angular distributions extracted for the prominent levels of ^{16}O. The group at 14—15 MeV was treated as a single level. These angular distributions are shown in Fig. 12. There are two principal features. First, while the cross sections for the 14.5- and 16.2-MeV levels increase by factors of 2—3 between the (^{6}Li,d) and (^{7}Li,t) reactions, those for the 20.7-MeV level decrease by a factor of two. Second, for the (^{7}Li,t) reaction, the angular position of the maximum for the 20.7-MeV level is about 5° larger than those for the other levels, possibly suggesting a larger L transfer.

In attempting to understand the nature of the level at 20.7 MeV, transmission coefficients have been calculated for ^{6}Li(^{7}Li) scattering from ^{12}C, and deuteron (triton) scattering from ^{16}O at center-of-mass energies appropriate for population of the various excited states of ^{16}O. Both reactions favor an angular-momentum transfer of approximately 8 units. Thus the difference in relative cross sections for the two reactions is unexplained.

A phase-shift analysis[4] of alpha scattering from ^{12}C indicates the presence of states with $J^\pi = 5^-$ and 7^- near 20.8 MeV in ^{16}O. The $J^\pi = 7^-$ level is considered to be a member of the first odd-parity rotational band. However, the $J^\pi = 1^-$ and 3^- levels are very weakly populated in these α-transfer reactions.[1,5]

[4] E. B. Carter, Phys. Letters 27B, 202 (1968).

[5] A. A. Ogloblin, Nuclear Structure, Dubna Symposium, 1968 (International Atomic Energy Agency, Vienna, 1968), p. 204.

A more attractive interpretation of the 20.7-MeV state is that it is the $J^\pi = 8^+$ member of the first even-parity rotational band in ^{16}O, which is believed to have predominantly 4p-4h character. Its reduced intensity relative to the 16.2-MeV state ($J^\pi = 6^+$) can be accounted for by the fewer configurations available. Restricting four particles to T=0 states in the s-d shell, eight configurations are available for a 6^+ state, but only two for an 8^+ state.

Such an identification of a $J^\pi = 8^+$ state would be in agreement with theoretical calculations[6,7] and would confirm the kinking of the first even-parity rotational band as predicted by these calculations.

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[6] I. Kelson, Phys. Letters 16, 143 (1965).

[7] L. S. Celenza, R. M. Dreizler, A. Klein, and G. J. Dreiss, Phys. Letters 23, 241 (1966).

ELASTIC SCATTERING OF ^{16}O BY ^{18}O FROM 30 TO 50 MeV

H. T. Fortune, A. Richter, R. H. Siemssen, and J. W. Tippie*

The content of this paper is included in the more comprehensive report on p. 15.

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*Applied Mathematics Division.

THE (^3He, ^7Be) REACTION ON LIGHT NUCLEI

H. T. Fortune and B. Zeidman

As part of a program for the investigation of heavy ions resulting from light-ion interactions with nuclei, targets of ^{11}B, ^{12}C, ^{16}O, and ^{28}Si were bombarded with 35.5-MeV ^3He ions and all emergent particles with $A > 4$ were detected simultaneously in a counter telescope. For all targets, some of the largest cross sections were obtained for reactions yielding ^{7}Be particles in the final state. Angular distributions have been measured for the (^{3}He, ^{7}Be) reaction in the forward quadrant with an overall system resolution of less than 75 keV. The 0.431-MeV state of ^{7}Be was resolved from the ground state at angles less than $\sim 45^{\circ}$, a point at which kinematic broadening prevents their resolution. For ^{12}C, the cross section for the (^{3}He, ^{7}Be) reaction is larger than for any of the others—perhaps because of the α-particle structure of ^{12}C. The angular distributions for the two bound states of ^{7}Be differ markedly, that of the $\frac{3}{2}^{-}$ state possessing more pronounced oscillations and its cross section being approximately twice that of the $\frac{1}{2}^{-}$ state. Preliminary data have also been obtained for several other light targets.

THE ^{40}Ca(^{16}O, ^{12}C)^{44}Ti REACTION AND STATES IN ^{44}Ti

A. M. Friedman,* H. T. Fortune, G. C. Morrison, and R. H. Siemssen

The (^{16}O, ^{12}C) reaction on isotopes of calcium has been studied with a 48-MeV ^{16}O beam from the Argonne tandem Van de Graaff. The energy and mass of the emitted particles were determined with an E-ΔE silicon counter telescope and electronic particle identification. The ΔE detector was 15 μ thick. Analyses of the ^{12}C spectra from the ^{40}Ca(^{16}O, ^{12}C) reaction indicate states in ^{44}Ti at excitation energies of 0.0, 1.09, 2.50, 3.35, 4.01, 4.82, 6.01, and 6.45 MeV. The measured angular distributions are peaked forward and vary smoothly with angle. The low-lying states observed are in agreement with recent results from ^{40}Ca(α, γ) and ^{46}Ti(p, t) measurements.

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AMBIGUITIES IN THE IMAGINARY PART OF THE HEAVY-ION OPTICAL POTENTIAL

J. V. Maher, R. H. Siemssen, M. Sachs,* A. Weidinger,* and D. A. Bromley*

The recently reported[1] continuous ambiguity in the imaginary part of the heavy-ion optical potential has been investigated by searching on synthetic cross sections calculated from the potential which had been found[2] to reproduce the strong diffraction-like structure of the $O^{16} + O^{16}$ elastic scattering. These calculations show that this ambiguity holds even in this extreme case. It is found that the ambiguity in principle can be resolved by appeal to the energy dependence of the calculated cross sections, although for the present case the differences between the various sets of predicted cross sections are too small to allow this distinction to be drawn confidently. The energy dependences of W for fixed geometrical parameters are linear with different slopes over a wide range of radii. The significance of "deep" or "shallow" imaginary potentials has been investigated.

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*Wright Nuclear Structure Laboratory, Yale University, New Haven, Connecticut.

[1] E. H. Krubasik, H. Voit, E. Blatt, H. D. Helb, and G. Jschenko, Z. Physik 219, 185 (1969).

[2] R. H. Siemssen, J. V. Maher, A. Weidinger, and D. A. Bromley, Phys. Rev. Letters 19, 369 (1967); 20, 175 (1968).

THE MIDWEST TANDEM CYCLOTRON PROPOSAL

G. C. Morrison

This report is a summary of Argonne National Laboratory Report ANL-7582. A comparable summary will be found in ANL-7620, pp. 113—124.

ELASTIC SCATTERING OF ^{6}Li ON ^{6}Li

G. C. Morrison, H. T. Fortune, and R. H. Siemssen

In order to extend our information on the interaction between identical nuclei, the elastic scattering of ^{6}Li on ^{6}Li has been studied in the bombarding energy range 9—34 MeV. The experiment utilized a large array of detectors and the associated-particle method for particle detection and identification. The coincident spectra for each pair of detectors was recorded in a 64×128 two-dimensional matrix. Excitation functions were obtained in steps of 250 keV at c.m. angles 60°, 70°, 80°, and 90°. Detailed angular distributions were also measured at 12, 20, and 28 MeV laboratory energy. We are attempting to interpret the data by optical-model calculations.

OXYGEN ELASTIC SCATTERING FROM THE EVEN-MASS MAGNESIUM AND SILICON ISOTOPES

R. H. Siemssen, H. T. Fortune, A. Richter, and J. L. Yntema

The content of this paper is included in the more comprehensive report on p. 15.

COMPUTER-CONTROLLED MULTIPLE-DETECTOR ARRAY FOR HEAVY-ION EXPERIMENTS

R. H. Siemssen, H. T. Fortune, J. W. Tippie,* and J. L. Yntema

The content of this paper is included in the more comprehensive report on p. 15.

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*Applied Mathematics Division.

Conference on Computational Physics

Abingdon, England, 28 July—1 August 1969

A SYSTEMS APPROACH TO THE NUCLEAR SHELL MODEL

S. Cohen

Computational Physics, Proceedings of the Conference Held at Culham Laboratory, July 1969, Vol. 1: Invited Papers (UKAEA Culham Laboratory, Abingdon, Berkshire, England, 1969), Report No. CLM-CP (1969), Session VII, pp. H1-H17

Theoretical studies of nuclear structure rely heavily on calculations using an independent-particle model similar to the shell model of atomic structure. A typical nuclear shell-model calculation involves several different steps. First a complete set of basis states is constructed. The matrices of the model Hamiltonian in this basis are then constructed and diagonalized. Finally the resultant eigenvalues and eigenvectors are used to make theoretical predictions of experimentally measured quantities.

A large digital computer is an indispensable tool in such studies. Very few special algorithms are needed, beyond those common to all scientific studies, and the input parameters and final results are quite small sets of numbers. The greatest difficulty is posed by the vast amount of intermediate data generated by the calculation.

In a systematic approach to the problem, an open-ended evolutionary system called DELPHI has been constructed. This system is easily alterable and can be expanded to include features needed to explore new avenues of investigation. Its built-in growth capability provides users of the system with an ever-increasing power to tackle new problems.

DELPHI has been designed to cater to the needs of scientists relatively unskilled in the use of computers. The facilities provided range from documentation techniques and large libraries of coherently designed algorithmic subroutines to automatic means of managing the dynamic storage of data. They also include a user-oriented language called SPEAKEASY, designed to make short investigations even more direct. In all cases the design specifications are such as to aid the scientist in obtaining answers to his problems quickly.

The growth capability has already led to the use of the system in ways not originally contemplated; extensions of the system to allied fields of study in nuclear physics are already under way.

Second IAEA Symposium on the Physics and Chemistry of Fission

Vienna, Austria, 28 July—1 August 1969

SHORT-LIVED SPONTANEOUSLY FISSIONING ISOMERS IN NEUTRON-INDUCED FISSION

A. J. Elwyn and A. T. G. Ferguson*

Physics and Chemistry of Fission (International Atomic Energy Agency, Vienna, 1969), pp. 457-460

This paper reports measurements of the half-lives and production cross sections for spontaneously fissioning isomers induced in isotopes of U and Pu by fast neutrons of energy 2.2 and 0.55 MeV.

Neutrons in pulses of about 1 nsec duration are generated by the 3-MeV pulsed proton beam from the IBIS Van de Graaff machine. For production of 2.2-MeV neutrons, a Mo-windowed tritium gas target was used and for the 0.55-MeV neutrons a Li-metal target was employed. The fissile samples were deposits 1.5 mg/cm^2 thick in the form of oxides on platinum backings. Fission fragments were detected in a Si surface-barrier counter and the time distribution of the pulses was measured relative to the proton beam pulse with a time-to-amplitude converter.

With the experimental arrangement at the IBIS accelerator, the intensity of any residual beam between beam bursts in the machine is found to be less than about 10^{-6} of the main beam intensity. Thus, the time distribution of the pulses in any, even weakly excited, delayed fission process could be observed quite cleanly.

Figure 13 shows the time distribution of the pulses following neutron bombardment of the ^{239}Pu sample. The large peak near channel number 855 corresponds to the prompt fission of ^{239}Pu, induced by 2.2-MeV neutrons. In an analysis of the events in the "tail" of this peak, the observed distribution is found to be consistent with the existence of two short-lived activities; one is fairly intense

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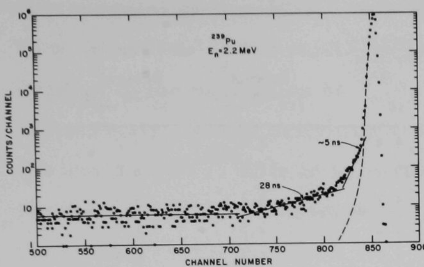

Fig. 13. Time distribution of the pulses due to fission fragments following the bombardment of ^{239}Pu with a 1-nsec pulse of 2.2-MeV neutrons. Time increases toward the left in this figure. The time calibration is 0.92 nsec/channel. The half-lives (nsec) of observed activities are indicated in the figure. The dashed curve is representative of the shape of the distribution associated with the prompt-fission events.

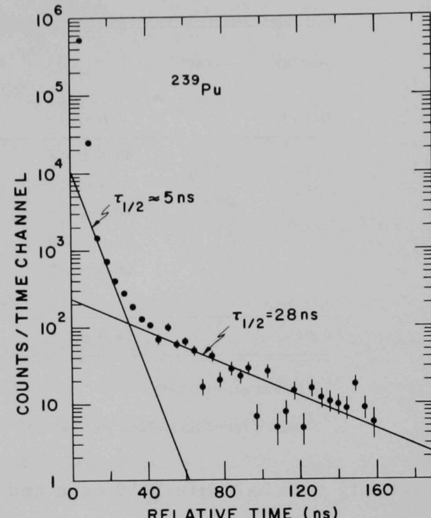

Fig. 14. Number of net counts in a 4.6-nsec time channel as a function of time measured from the prompt-fission peak. The straight lines indicate the half-lives determined analytically from the data.

with a 5-nsec half-life, while the second is weaker with a half-life of ~28 nsec. Figure 14 shows more clearly the analysis of the events in this tail after a small background of time-independent counts has been subtracted. In a similar manner, analyses of the distributions for the U isotopes are, except for ^{238}U, consistent with the existence of short-lived activities that have half-lives between 20 and 67 nsec. For ^{238}U no activity with a half-life greater than about 2 nsec was observed, and the shape of this distribution could be taken as representative of the shape of the "prompt" peak.

As a test, the time distribution of α particles in the $^{10}B(n,\alpha)^{6}Li$ reaction was obtained. On the basis of an analysis of this time distribution, it is concluded that for the fissile samples no

TABLE III. Table of results.

Energy (MeV)	Target	$\tau_{1/2}$ (nsec)	$R = \frac{\text{Delayed}^{a}}{\text{Prompt}}$ ($\times 10^{-4}$)	σ_{nf} Prompt[b] (10^{-24} cm^2)	σ_{nf} Delayed[a] (10^{-28} cm^2)
2.2	^{239}Pu	29.0 ± 3.8	4.1	2.0	8.2
		4.1 – 5.2	39	2.0	78.0
	^{233}U	30.4 ± 4.9	4.7	2.1	9.6
	^{234}U	19.7 ± 4.9	1.2	1.5	1.8
	^{235}U	66.6 ± 8.7	3.1	1.3	4.0
	^{238}U		No lifetime observed		
0.55	^{233}U	34.9 ± 4.5	7.4	2.0	15.0

[a]Error about ±50%.

[b]Taken from BNL-325, Ref. 4.

activity with half-life $\gtrsim$ 10 nsec and an intensity as great as $\sim 10^{-5}$ of the intensity of the "prompt" peak should be observed, if it is assumed that the neutrons responsible for any spurious "tail" have an energy close to that of the primary neutrons. For neutrons of any lower energy, this limit can be substantially reduced due to the increasing ratio of the (n, α) to prompt fission cross section at lower energies.

The results from analysis of the time distributions for the nuclei studied are shown in Table III. The half-lives and integrated intensities listed in columns 3 and 4 are based (except for ^{233}U at 0.55 MeV) on at least two independent runs for each sample, and involve the detection of not less than 7.5×10^6 events in the prompt peak. The errors quoted on the half-lives are based on a combination of the statistical uncertainties in the analysis, and on estimates of systematic errors in the experiment.

It is reasonable to assume that the observed activities are associated with nuclei produced in the (n, γ) reaction on the targets listed in Table III. For ^{240}Pu [produced in the ^{239}Pu(n, γ) reaction], as mentioned previously, two activities are observed. The 5-nsec half-life is in agreement with results reported by a number of experimental groups,[1—3] but the 29-nsec activity has not previously been observed. In the studies of the ^{233}U, ^{234}U, and ^{235}U samples (leading to the production of ^{234}U, ^{235}U and ^{236}U final nuclei, respectively), single activities were seen. The 67-nsec activity associated with ^{236}U is in agreement with other results.[1,3] No previous activity associated with ^{234}U and ^{235}U final nuclei have been reported.

In summary, the results shown in Table III suggest that short-lived spontaneously fissioning isomeric states are produced in ^{234}U, ^{235}U, ^{236}U, and ^{240}Pu in neutron-induced reactions. By demonstrating the apparent existence of more than one isomer in ^{240}Pu, this work emphasizes the complexity of the situation with regard to fissioning isomers.

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[1] N. Lark, G. Sletten, and S. Bjørnholm, in Proceedings of International Symposium on Nuclear Structure, Dubna (1968), p. 90; S. Bjørnholm (private communication).

[2] K. L. Wolf and R. Vandenbosch, Bull. Am. Phys. Soc. 13, 1407 (1968); Physics and Chemistry of Fission (International Atomic Energy Agency, Vienna, 1969), pp. 457-460.

[3] V. Metag, R. Repnow, P. von Brentano, and J. D. Fox, in Ref. 2.

Sixth International Conference on the Physics of Electronic and Atomic Collisions

Cambridge, Massachusetts, 28 July—2 August 1969

PHOTOELECTRON SPECTROSCOPY OF AUTOIONIZATION PEAKS

J. Berkowitz and W. A. Chupka

Abstracts of Papers (Massachusetts Institute of Technology, Cambridge, Massachusetts, 1969), p. 192

A vacuum ultraviolet monochromator has been combined with a retarding-field electron energy analyzer to study the distribution of photoelectrons from autoionizing states of hydrogen and nitrogen. The five most intense lines of hydrogen were studied in the photon energy range above the threshold of H_2^+, v = 1. These quasi-discrete states do not have sufficient energy to autoionize by $\Delta v = -1$, and hence the experimental data cannot test this propensity. However, in most cases involving hydrogen, the photoelectrons produced are monoenergetic and correspond to autoionizing transitions in which Δv is a minimum, i.e., the ejected electrons have the minimum kinetic energy. The calculations of Nielsen and Berry[1] tend generally to support this observation, but when Δv exceeds -2, the calculations are apparently less reliable; they sometimes predict reversals which are not observed experimentally and at other times do not predict reversals that are observed experimentally.

Eight autoionization bands and one window resonance have been explored in the photon energy region above the threshold for N_2^+, v = 1. Different mechanisms appear to be operative in the nitrogen autoionizations. In general, several monoenergetic groups of electrons corresponding to the formation of several ionic states, are observed. Whereas vibrational relaxation of the core appears to explain the results with hydrogen, an alternative mechanism involving configuration interaction has been examined in an attempt to rationalize

[1] S. E. Nielsen and R. S. Berry, Chem. Phys. Letters 2, 503 (1968).

the nitrogen results. This proposed mechanism[2] implies that relative transition probabilities in the autoionization process are dominated by Franck-Condon factors connecting the quasi-discrete state and the ionic state.

The ratio of Franck-Condon factors is very sensitive to the choice of internuclear distance for the quasi-discrete state. Calculations have been made within the harmonic-oscillator approximation, and also with some reasonable anharmonicities. In many cases, it is possible to find a plausible internuclear distance for which the ratio of Franck-Condon factors agrees with experiment. Since the autoionization peaks are broadened by autoionization, a rotational analysis is not possible and hence a comparison of r_e obtained by this technique and spectroscopic analysis cannot be made. If the Franck-Condon factors are indeed the major determinant of relative transition probabilities, photoelectron spectroscopy offers a method for determining the internuclear distances of the quasi-discrete states. It also provides a means for determining whether the Rydberg electron is bonding or antibonding, and therefore assists in selecting the symmetry of this orbital. One autoionizing transition in nitrogen, as yet unassigned, does not easily fit into the configuration-interaction mechanism, nor is it readily explained by the vibrational-relaxation mechanism.

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[2] J. N. Bardsley, J. Phys. B 1, 349 (1968); Chem. Phys. Letters 2, 329 (1968).

A STUDY OF SOME REACTIONS OF H_2^+ IN SELECTED VIBRATIONAL STATES

W. A. Chupka, J. Berkowitz, and M. E. Russell

Abstracts of Papers (Massachusetts Institute of Technology, Cambridge, Massachusetts, 1969), p. 71

Photoionization[1] with photons of narrow band width (0.14 Å) was used to produce H_2^+ ions in specific vibrational states from v = 0 to v = 5. The reactions of these ions with helium has been studied as a function of kinetic energy in the range 0—10 eV. The reactions studied were

$$H_2^+ + He \rightarrow HeH^+ + H, \quad (1)$$

$$H_2^+ + He \rightarrow H^+ + H + He. \quad (2)$$

Earlier work[2] had shown that reaction (1), which is endoergic by about 0.80 eV, occurs for H_2^+ ions with $v \geqslant 3$. The cross section at thermal kinetic energies increases rapidly with increasing vibrational excitation of the reactant ion. In the present study, the kinetic energy of the reactant ion was varied from 0 to 10 eV by varying the repeller voltage in the ionization chamber. Values of the phenomenological cross section Q were measured with high relative accuracy as a function of kinetic energy by a repetitive scanning technique which employs a multichannel scalar. Microscopic cross sections as a function of kinetic energy were then obtained from the data by use of the expression given by Light.[3] The final results for H_2^+ with v = 0 and v = 3 are shown in Figs. 15 and 16. Similar curves have been obtained for H_2^+ in all vibrational states from 0 to 5, inclusive. The following conclusions are immediately apparent from the data. H_2^+ in any vibrational state will react according to both (1) and (2). The threshold for the reaction occurs at the

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[1] J. Berkowitz and W. A. Chupka, J. Chem. Phys. 45, 1287 (1966); W. A. Chupka and J. Berkowitz, J. Chem. Phys. 47, 2921 (1967).

[2] W. A. Chupka and M. E. Russell, J. Chem. Phys. 49, 5426 (1968).

[3] J. C. Light, J. Chem. Phys. 41, 586 (1964).

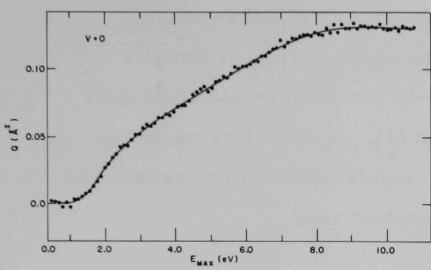

Fig. 15. Cross section vs kinetic energy for reactions (1) and (2), with H_2^+ (v = 0).

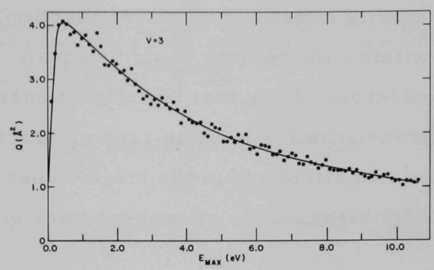

Fig. 16. Cross section vs kinetic energy for reactions (1) and (2), with H_2^+ (v = 3).

calculated value, i.e., there is no evidence for excess activation energy. Even well above threshold, the cross section for both reactions is strongly dependent on the vibrational energy of the H_2^+ ion. The form of the cross-section curves (e.g., Figs. 15 and 16) are very similar to the analogous curves calculated by Karplus et al.[4] for the isoelectronic reaction

$$T + H_2 \rightarrow TH + H. \quad (3)$$

In order to assess the relative effectiveness of vibrational energy and kinetic energy in causing reaction (1) to occur, the cross sections for this reaction were displayed (Table IV) for H_2^+ in the vibrational states with v = 0—5 and for total center-of-mass internal energy E_t = 1.0, 2.0, 3.0, and 4.0 eV. The values shown have been corrected for the variation of the Langevin cross section—though this correction is very much less than the differences shown in the table. If vibrational and kinetic energy were

TABLE IV. Cross section values for reaction (1) as a function of total energy content and vibrational quantum number.

v	Cross section (Å^2)			
	E_t = 1.0 eV	2.0 eV	3.0 eV	4.0 eV
0	0.06	0.10	0.13	0.17
1	0.49	0.35	0.31	0.25
2	1.95	0.93	0.55	0.34
3	. . .	1.70	0.99	0.56
4	. . .	2.35	1.22	0.68
5	. . .	2.49	1.70	0.89

[4] M. Karplus, R. N. Porter, and R. D. Sharma, J. Chem. Phys. 45, 3871 (1966).

equally effective in causing reaction, the values of cross section within each column would be equal. The large variation actually observed shows that vibrational energy is much more effective than translational energy in causing reaction (1). Part of this variation can be attributed to the large values of angular momentum associated with higher translational energies of reactant ions.

International Symposium on Neutron Capture Gamma-Ray Spectroscopy

Studsvik, Sweden, 11—15 August 1969

THERMAL-NEUTRON CAPTURE GAMMA-GAMMA COINCIDENCE STUDIES AND TECHNIQUES

H. H. Bolotin

Neutron Capture Gamma-Ray Spectroscopy (International Atomic Energy Agency, Vienna, 1969), pp. 15-34

The advantageous use of gamma-gamma coincidence techniques in slow-neutron capture gamma-ray spectroscopic investigations is examined and the unique information derived from such studies is compared with that obtained by more conventional spectroscopic methods. The feasibility, practicality, and value of gamma-gamma coincidence studies performed with the exclusive use of Ge(Li) detectors are clearly demonstrated. It is shown that the clarity of the data and the unequivocal information gleaned from the use of this technique are clearly superior to previously employed NaI(Tl)-Ge(Li) coincidence systems. Salient details of the method are described. Several examples of data obtained with the use of the Ge(Li)-Ge(Li) coincidence method are presented. It is concluded that widespread use of these coincidence techniques should provide a significant contribution to the understanding of the level structure of nuclides studied in slow-neutron capture gamma-ray reaction experiments.

LEVEL STRUCTURE OF LOW-LYING EXCITED STATES OF ^{187}W

H. H. Bolotin and D. A. McClure

Neutron Capture Gamma-Ray Spectroscopy (International Atomic Energy Agency, Vienna, 1969), pp. 389-402

The low-lying excited states of ^{187}W populated by primary and secondary γ-ray transitions from the $^{186}W(n, \gamma)^{187}W$ thermal-neutron-capture reaction were studied. Ge(Li) detectors were used exclusively in both singles and coincidence γ-ray investigations. Coincidence investigations between high-energy ($\sim$4—5.5 MeV) and low-energy ($\leq$ 1200 keV) γ rays, as well as among the low-energy transitions have allowed a total of 74 low-energy transitions to be assigned between states up to an excitation energy of 1217 keV. Several new levels have been inferred and the decay properties of all states observed have been established. The observed characteristics of these states are compared with the most recent (d, p) studies and a rotational model that includes Coriolis band mixing.

USE OF AVERAGE-RESONANCE-CAPTURE MEASUREMENTS FOR NUCLEAR SPECTROSCOPY

R. K. Smither and L. M. Bollinger

<u>Neutron Capture Gamma-Ray Spectroscopy</u> (International Atomic Energy Agency, Vienna, 1969), pp. 601-605

Average-resonance-capture measurements have proved to be a valuable way to study the statistical properties of the neutron-capture process. They are also a powerful spectroscopic tool. In favorable cases it is possible to determine the parity and restrict the choice of the spin to two values for 20 to 30 levels of the nucleus. The basic approach is quite simple. The neutron-capture process is spread out over many neutron resonances so that no one resonance contributes more than a few per cent of the radiative capture. This averages out the Porter-Thomas fluctuations of the radiation widths of individual gamma rays associated with a single resonance and allows one to identify the multipolarity of the transition by its characteristic gamma intensity.

Figure 17 illustrates this approach. On the left is shown the neutron capture into many levels and the subsequent emission of primary gamma rays. On the right is the predicted distribution of radiation widths based on the Porter-Thomas theory. When the gamma strength is averaged over many resonances, the average

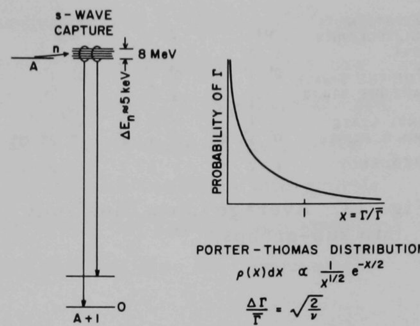

Fig. 17. Left: Neutron capture into many levels followed by primary gamma rays. Right: Predictions for the distribution of radiation widths.

fractional deviation $\Delta\Gamma/\Gamma$ is given by the expression

$$\Delta\Gamma/\Gamma \approx \sqrt{2/\nu}\,,$$

where ν is the number of resonances used in the average. In our experiments $\nu \approx 200$ so that $\Delta\Gamma/\Gamma \approx 0.10$, i.e., 10% of the average value. The averaging is done by surrounding the neutron-capturing sample by enough boron ($\frac{1}{16}$ — $\frac{1}{8}$ in.) to strongly absorb all the incident neutrons with energies below 100 eV. This eliminates the strong low-energy neutron resonance from the capture process and leaves only the neutron capture in the numerous weak resonances above 100 eV to be averaged. The sample is placed in the high-flux region of the Argonne research reactor in the center of a 5-in.-diameter through tube. The gamma rays are brought out through a set of collimators and detected by a Ge(Li) detector. The Ge(Li) detector is incorporated in a large pair spectrometer (split ring of NaI, 12-in. diam.) to suppress Compton, single-escape, and full-energy peaks.

In general, the average E1 radiation is a factor of 8 to 12 stronger than the M1 radiation, which results in two easily separated groups. These average intensities are further split into subgroups according to the spin of the final state. This is shown in Fig. 18, where we consider the case of neutron capture in ^{111}Cd and ^{113}Cd, whose capturing state is $\frac{1}{2}^+$. For dipole radiation, the strength to the J=1 levels is twice as strong as it is for the J=0 or J=2 ones. Furthermore, the presence of E2 radiation enhances the strength to the 1^+ and 2^+ states over that to the 0^+ states and generates some

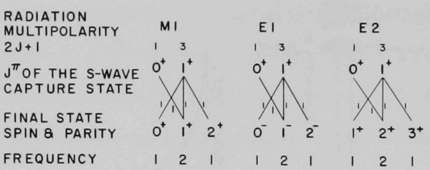

Fig. 18. Average intensities split into sub-groups.

transition strength to the 3^+ states. Much the same type of enhancement results from p-wave capture followed by E1 transitions; and in the region A = 85—135, the p-wave contributions will often be stronger than the E2 component.

Figure 19 is an example of the data taken by Smither and Buss with an enriched sample of ^{111}Cd. The predicted enhancement of the 2^+ lines over the 0^+ lines is quite obvious.

When the p-wave strength is appreciable, it will of course be present in all the transitions in which it is possible and can be detected by the change in the line shape of the peak in the Ge(Li) detector. This difference in shape can be used to distinguish E1 transitions from M1 or E2 transitions and is used as a check on the multipole assignments of the lines.

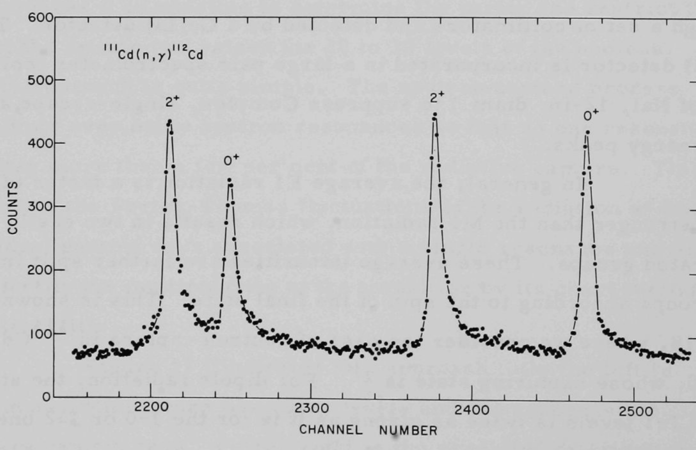

Fig. 19. Spectrum from an enriched cadmium sample, showing the enhancement of 2^+ lines over 0^+ lines.

The experimental results for the $^{113}Cd(n,\gamma)^{114}Cd$ reaction are shown in Fig. 10. The filled squares and circles are known 2^+ and 0^+ levels, respectively. The relative intensity plotted is the observed gamma intensity divided by the cube of the gamma energy ($I_{rel} = I_\gamma / E^3$). The separation of the intensities into groups associated with a single spin value is due to the appreciable amounts of s-wave capture plus E2 and p-wave capture plus E1 components in the spectrum.

Of the 38 nuclides studied to date, 16 have been analyzed. The results for $^{112,114}Cd$, ^{126}Te, $^{148,150}Sm$, $^{156,158}Gd$, ^{166}Ho, ^{168}Er, $^{178,180}Hf$, ^{182}Ta, $^{188,190}Os$, and ^{196}Pt were found to be in agreement with the general pattern predicted from the statistical model; only ^{170}Tm failed to follow the expected pattern. The nuclides for which the analysis is incomplete are ^{74}Ge, ^{92}Zr, ^{94}Nb, $^{96,98}Mo$, $^{100,102}Ru$, ^{106}Pd, $^{118,120}Sn$, ^{134}Cs, ^{136}Ba, ^{138}B, $^{162,164}Dy$, $^{172,174}Yb$, ^{184}W, ^{194}Au, $^{200,202}Hg$, and ^{239}U.

RECENT IMPROVEMENTS IN THE ARGONNE 7.7-m BENT-CRYSTAL SPECTROMETER

R. K. Smither and D. J. Buss

Neutron Capture Gamma-Ray Spectroscopy (International Atomic Energy Agency, Vienna, 1969), pp. 55-63

Recent improvements to the Argonne 7.7-m bent-crystal spectrometer have lead to a doubling of its resolving power and to at least a 4-fold improvement in its sensitivity (ratio of diffraction peak to background) over the whole range of the spectrometer, and an improvement of 20-fold or more above 2 MeV. The energy range of the spectrometer was extended to cover the full (n,γ) spectrum from 20 keV to 6 MeV.

The new configuration of the spectrometer is shown in Fig. 20. An example of some experimental results obtained at 6 MeV is shown in Fig. 21.

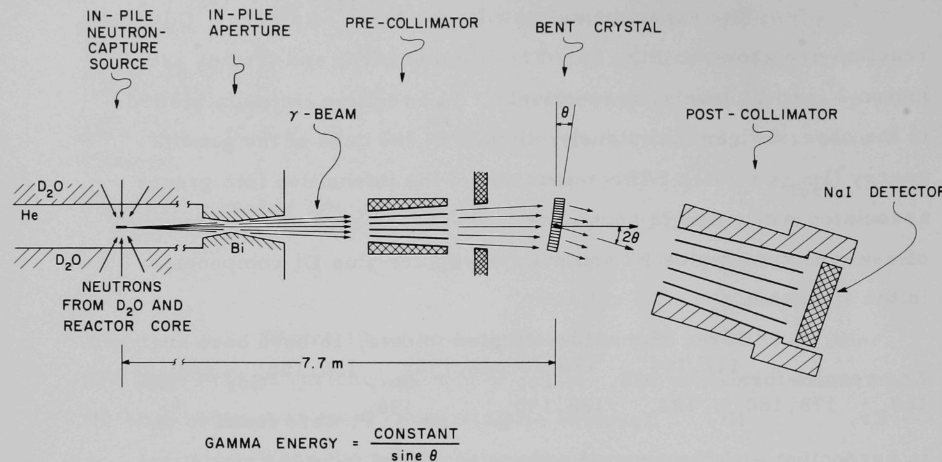

Fig. 20. Diagram of the bent-crystal spectrometer with the multislit pre-collimator in place. The gamma rays result from neutron capture in a small sample at the left, near the core of the reactor. They emerge from the reactor through a Bi aperture and pass through the pre-collimator and a second aperture. A narrow energy increment of this gamma beam is then diffracted by the (310) planes of the bent crystal, separated from the undiffracted beam by the post-collimator, and finally detected by a band of ten NaI crystals.

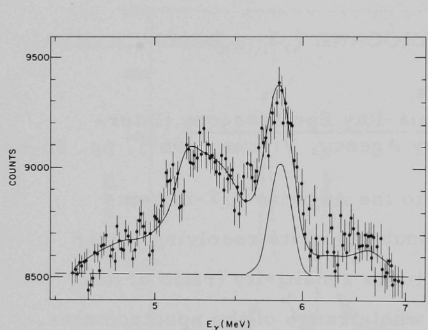

Fig. 21. A bent-crystal spectrometer run over the strong 5.8-MeV line in the $^{113}Cd(n, \gamma)^{114}Cd$ spectrum. It was obtained with the first-order diffraction of the (310) planes in quartz. The solid line is the envelope of the known spectral components in this energy region; it is based on Ge(Li) data normalized to the experimental counting rate. A single line shape of appropriate height for the 5.8-MeV line is also shown. The dashed line is the undiffracted background.

LOW-LYING ROTATIONAL BANDS IN ^{153}Sm

R. K. Smither and T. von Egidy*

Neutron Capture Gamma-Ray Spectroscopy (International Atomic Energy Agency, Vienna, 1969), pp. 355-358

A series of (n, γ) and (n, e$^-$) experiments were used to develop the level scheme of ^{153}Sm. Unique spin and parity assignments were made for 15 of the 25 levels below 700 keV. The low-energy part of the level scheme is shown in Fig. 22. The most interesting feature of the low-energy levels shown in Fig. 22 is that they can be divided into rotational bands in such a way that the relative intensities of the competing gamma transitions from each level can be explained with the Nilsson model[1] without introducing any band mixing. Although the widths of the shaded portions of the lines in Fig. 22 are meant to suggest the γ intensities of the transitions, it is much easier to compare their relative intensities with the theoretical predictions after the relative energy factors are removed. This is done in Fig. 23. The experimental J^π assignments are given on the left. The proposed J^π assignment is given to the right of each of the three rotational bands whose individual levels are shown as extra-thick lines. The upper portion of the figure includes all of the detected M1 and E2 transitions, while the lower section includes all the E1 transitions originating from the ten levels included in the three rotational bands. The width of each transition is proportional to its normalized γ intensity $I_N = \text{constant} \times I_\gamma / E_\gamma^3$. The labels on the transitions indicate the lowest possible multipole assignment that is consistent with the proposed spin and parity assignments. No transitions are left out. The dashed lines indicate missing transitions that may be

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*Physikdepartment der Technischen Hochschule, München, Germany.

[1] S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. 29, No. 16 (1955); A. K. Kerman, in Nuclear Reactions, edited by P. M. Endt (North-Holland Publishing Co., Amsterdam, 1959), Vol. I, p. 427.

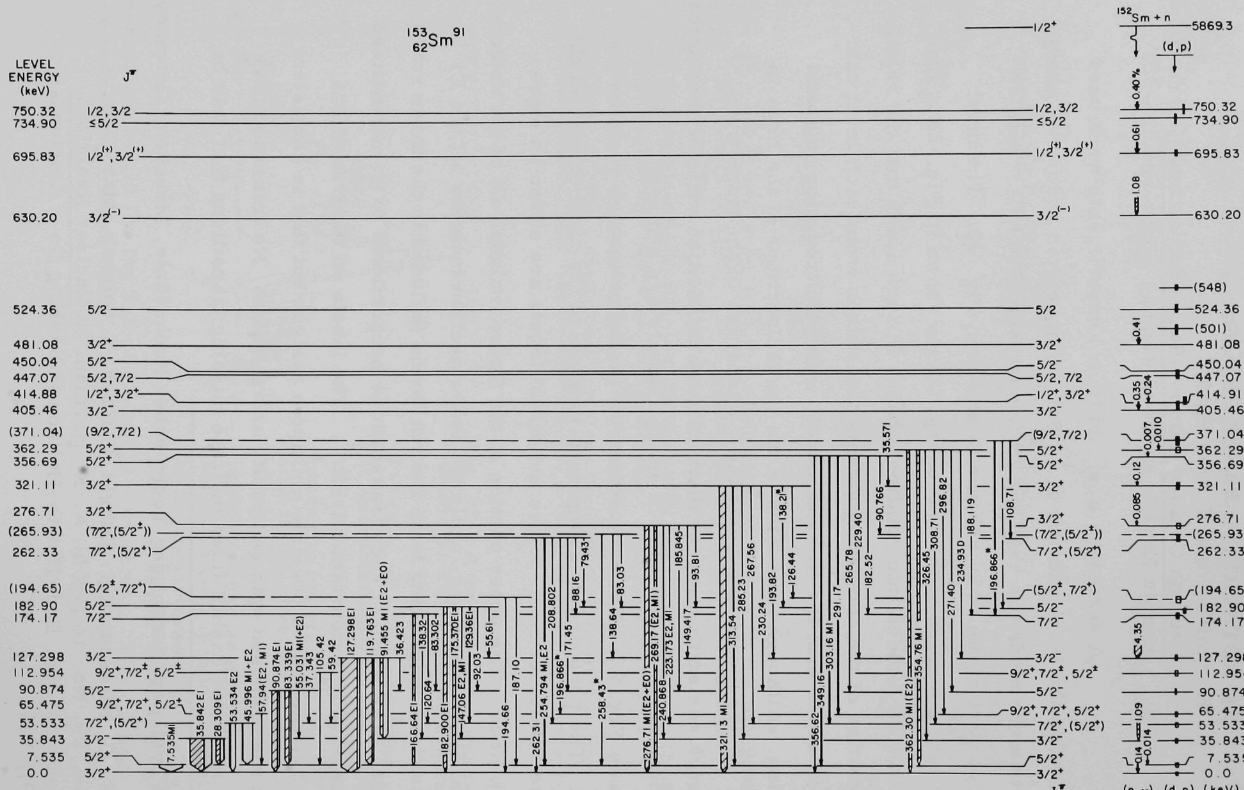
$^{153}_{62}Sm^{91}$
LEVEL ENERGY (keV)
J^{π}
750.32 1/2, 3/2
734.90 ≤5/2
695.83 $1/2^{(+)}, 3/2^{(+)}$
630.20 $3/2^{(-)}$
524.36 5/2
481.08 $3/2^{+}$
450.04 $5/2^{-}$
447.07 5/2, 7/2
414.88 $1/2^{+}, 3/2^{+}$
405.46 $3/2^{-}$
(371.04) (9/2, 7/2)
362.29 $5/2^{+}$
356.69 $5/2^{+}$
321.11 $3/2^{+}$
276.71 $3/2^{+}$
(265.93) $(7/2^{-}, (5/2^{\pm}))$
262.33 $7/2^{+}, (5/2^{+})$
(194.65) $(5/2^{\pm}, 7/2^{+})$
182.90 $5/2^{-}$
174.17 $7/2^{-}$
127.298 $3/2^{-}$
112.954 $9/2^{+}, 7/2^{\pm}, 5/2^{\pm}$
90.874 $5/2^{-}$
65.475 $9/2^{+}, 7/2^{+}, 5/2^{+}$
53.533 $7/2^{+}, (5/2^{+})$
35.843 $3/2^{-}$
7.535 $5/2^{+}$
0.0 $3/2^{+}$
$^{152}Sm + n$ 5869.3
(d,p)
(548)
(501)
414.91
(n,γ) (d,p) (keV)

Fig. 22. The level scheme of ^{153}Sm, showing the low-energy transitions originating from levels below 400 keV. The spin and parity assignments come from the (n, γ) and (n, e$^-$) data. The widths of the shaded lines suggest the gamma intensities of the corresponding transitions. When the conversion-electron intensity is appreciable, it appears as an unshaded portion of the line. The labels on the transitions give their energies (in keV) and multipole assignments. The vertical arrows on the right-hand side of the level scheme indicate the presence of direct (n, γ) transitions from the neutron-capture state. The energy levels from the early (d, p) work of R. A. Kenefick and R. K. Sheline [Phys. Rev. 139, B1479 (1965)] appear on the right-hand side of the level scheme as solid bars whose vertical heights reflect the uncertainties in their energies. The open bars correspond to the levels added in the recent (d, p) and (d, t) work [R. K. Sheline, in Nuclear Structure, Dubna Symposium, 1968 (International Atomic Energy Agency, Vienna, 1968), p. 71; and private communication]. The spin and parity assignments are repeated on the right-hand side of the level scheme. The parentheses around some of the level energies reflect some uncertainty in the method used to determine them.

hidden under lines of almost the same energy. The width of each dashed line represents the normalized upper limits of its intensity. The experimental upper limits on the normalized intensities of the other missing transitions are much smaller than these. The ground state and nine of these levels below 300 keV are interpreted as members of three $K=\frac{3}{2}$ rotational bands (two of negative parity and one of positive parity). The observed gamma-ray branching ratios were compared with the predictions of the Nilsson model for an odd neutron coupled to a deformed core. In most cases the experimental ratios agreed with the theoretical predictions to ±10%. An attempt was made to extend this analysis to the higher levels but only limited success was achieved.

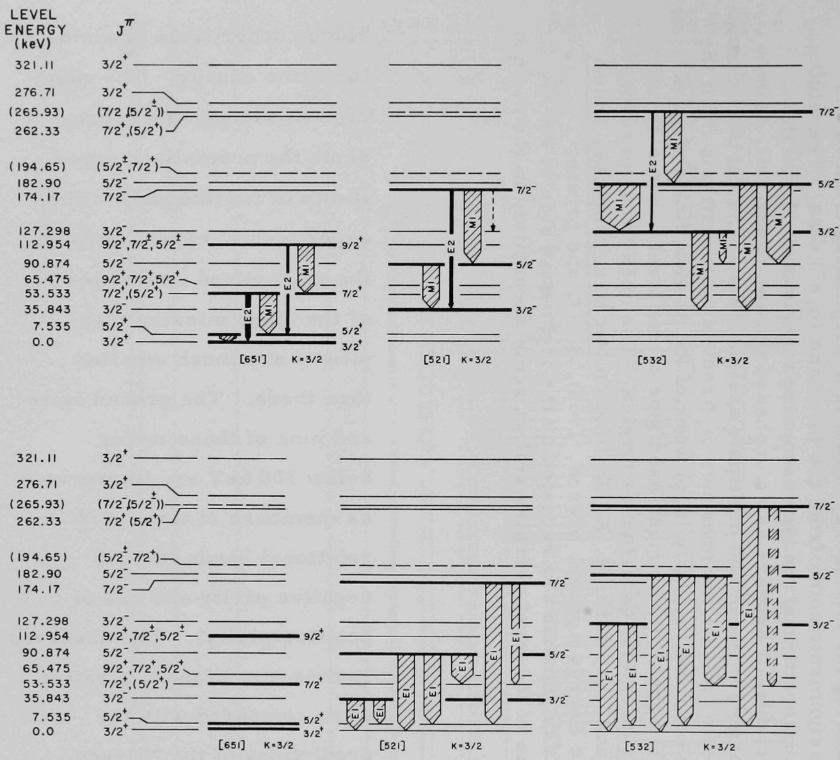

Fig. 23. The normalized gamma decay of the low-lying rotational band. Plot A shows the M1 and E2 transitions between levels with the same parity. Plot B shows E1 transitions between levels of different parity. The experimental values for the level energies (in keV) and for the spin and parity assignments are shown on the left. The proposed J^{π} assignments for the rotational bands are given to the right of each group. The width of each transition is proportional to its normalized γ intensity $I_N = \text{constant} \times I_{\gamma}/E_{\gamma}^3$. The label on a transition indicates the lowest possible multipole assignment that is consistent with the proposed spin and parity assignment. No transitions are left out. The dashed lines indicate missing transitions that may be hidden under lines of almost the same energy. The width of each dashed line represents the normalized upper limit of its intensity. The experimental upper limits on the normalized intensities of the other missing transitions are much smaller than these.

International Conference on Properties of Nuclear States

Montreal, Canada, 25—30 August 1969

STATES OF THE $(g_{9/2})^2$ CONFIGURATION IN Nb^{90}

R. C. Bearse, J. C. Stoltzfus, M. M. Stautberg, J. P. Schiffer, and J. R. Comfort

A similar report, presented as a Research Highlight, appears on p. 11.

PREDICTIONS FOR ^6Li BASED ON THE HAMADA-JOHNSTON POTENTIAL

R. D. Lawson

A similar report, presented at Rochester, appears on p. 47.

SPIN DEPENDENCE IN INELASTIC DEUTERON SCATTERING

J. C. Legg,* J. L. Yntema, R. C. Bearse, and H. T. Fortune

The excited-core model successfully describes the observed properties of many nuclei. Therefore in inelastic scattering from ^{63}Cu it is to be expected that a $\frac{1}{2}^-$, a $\frac{5}{2}^-$, and a $\frac{7}{2}^-$ state will be excited strongly with $\Delta\ell=2$ angular distributions similar to those for inelastic scattering to the 2^+ state in ^{62}Ni. Thankappen and True [Phys. Rev. 137, B793 (1965)] have successfully calculated the relative cross sections for these states, and further correctly predict that the $\frac{3}{2}^-$ excited-core state will have a much smaller cross section. For A = 60—70, the excited-core model successfully predicts all the major information obtained from inelastic scattering from odd-A nuclei.

*Kansas State University, Manhattan, Kansas.

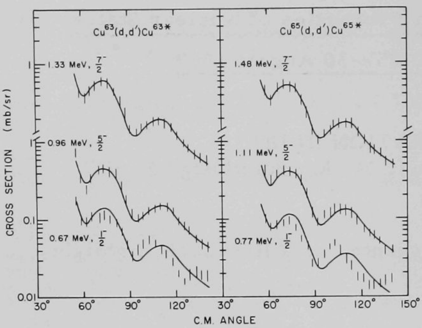

Fig. 24. Angular distributions of inelastically scattered deuterons from ^{63}Cu and ^{65}Cu.

A recently noted anomaly in $\Delta \ell = 2$ inelastic proton scattering [Legg and Yntema, Phys. Rev. Letters 22, 1005 (1969)] is explained neither by an excited-core model nor by the usual microscopic model of inelastic scattering. Specifically, the angular distributions from proton inelastic scattering leading to the $\frac{1}{2}^-$ states of ^{63}Cu, ^{65}Cu, and ^{67}Zn were found to differ significantly from those leading to the $\frac{3}{2}^-$, $\frac{5}{2}^-$, and $\frac{7}{2}^-$ states. Since the effect for $\frac{1}{2}^-$ states was observed regardless of ground-state spin, it was suggested that this was probably a final-state spin dependence. To see whether this spin dependence was an effect peculiar to protons or whether similar effects are observed in the inelastic scattering of other projectiles, we have studied the inelastic scattering of 14-MeV deuterons by ^{63}Cu and ^{65}Cu. The data (Fig. 24), taken with four E$\cdot$dE/dx telescopes in the 70-in. scattering chamber at Argonne, show the same smooth curve with each angular distribution. This curve was normalized to make the ratio of cross sections on the first maximum equal to that observed for proton scattering to the same states. The angular distributions for the $\frac{1}{2}^-$ states are obviously different at angles greater than 90° and there may be an effect on the secondary maximum similar to that reported for proton scattering. Thus, the spin dependence in the angular distributions has now been observed experimentally in both proton and deuteron inelastic scattering. This effect might be due to an $\vec{I} \cdot \vec{\ell}$ dependence in the optical model, but preliminary analysis of a recent study of the inelastic scattering of 21-MeV alpha particles by ^{63}Cu reveals a small, but probably significant, effect.

COULOMB ENERGIES AND NUCLEAR RADII

J. A. Nolen, Jr.,* and J. P. Schiffer

We have used available experimental results on Coulomb displacement energies between mirror nuclei and from isobaric analog states, under the assumption that isobaric spin is a good quantum number, to obtain information on nuclear matter radii. With the increasing precision of experimental data on nuclear charge radii from electron scattering and muonic x rays, such calculations lead to a reasonably precise value of the neutron radius. Exchange effects and the electromagnetic spin-orbit interaction were taken into account. Two unexpected features emerge. One is summarized in Table V: the radius of the excess nucleon or nucleons, from the one $d_{5/2}$ nucleon in O^{17} to the 44 excess nucleons in Pb^{208}, is always smaller by ~10%, relative to the core, than is predicted by any potential model. This either has to be a real anomaly in the radius of nucleons,

TABLE V. Experimental Coulomb displacement energies and rms charge radii, and a comparison between the ratios of neutron-excess to charge radii as calculated from these data and from a potential model.

Nucleus	Coulomb displacement energy (MeV)	Rms charge radius (fm)	Rms radius for excess / Rms radius of core: Data	Woods-Saxon potential	% difference
^{17}O	3.54	2.70	1.15	1.32	15
^{29}Si	5.73	3.10	1.13	1.22	8
^{33}S	6.35	3.25	1.07	1.10	4
^{41}Ca	7.28	3.49	1.03	1.20	17
^{48}Ca	7.18	3.48	1.06	1.23	16
^{62}Ni	9.38	3.87	1.05	1.18	12
^{120}Sn	13.70	4.64	1.05	1.18	11
^{208}Pb	18.87	5.51	1.08	1.16	8

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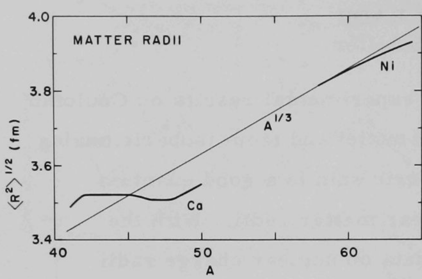

Fig. 25. Total rms radii of the nucleon distribution derived from the Ca and Ni data. These are shown by the heavy lines; the light line indicates an $A^{1/3}$ trend.

in orbits not filled for both protons and neutrons, or it implies a large (~5%) isospin-violating term in the Coulomb displacement energy.

The second effect is illustrated in Fig. 25. In the Ca isotopes the nuclear matter radius appears to be nearly constant from Ca^{41} to Ca^{48}. In a string of Ni isotopes, on the other hand, nuclear matter radii increase almost as rapidly as $A^{1/3}$. From the results we conclude that the addition of $f_{7/2}$ neutrons in the Ca isotopes has a very small polarizing effect on the Ca^{40} core while the addition of $2p\text{-}1f_{5/2}$ neutrons in the Ni isotopes polarizes the Ni^{56} core much more effectively. In the Sn isotopes the trend is similar to that observed in the Ni isotopes. Our neutron radius in Pb^{208} appears to be consistent with other experimental information. Calculations so far have been limited to closed-proton-shell nuclei for the sake of simplicity. This work has been published in Physics Letters.[1]

[1] J. A. Nolen, Jr., and J. P. Schiffer, Phys. Letters 29B(7), 396-398, 399-401 (23 June 1969).

American Physical Society

Hawaii, 2—4 September 1969

EFFECT OF CHANNELING ON THE CHARGE-CHANGING COLLISIONS OF ENERGETIC DEUTERONS PENETRATING THROUGH Ni(110) MONOCRYSTALS

M. Kaminsky

Bull. Am. Phys. Soc. 14, 846 (August 1969)

The equilibrium charge distribution of deuterium particles emerging from monocrystalline or polycrystalline Ni foils of various thicknesses was measured under ultrahigh-vacuum conditions for average energies $\overline{E}_m$ = 90—800 keV in the emergent beam. Over four times the area actually struck by the beam, each foil thickness varied $\lesssim 3\%$. The angular spread of the incident D^+ beam was $< 0.01°$ and its direction was parallel (within 0.1°) to the [110] axis of the Ni(110) foil and was normal to the polycrystalline foil. The emerging particles were analyzed electrostatically and R(emergent beam) = $D^0/(D^0 + D^+)$ was determined for different $\overline{E}_m$ values. For polycrystalline targets, R decreased from 0.480 to 0.004 as $\overline{E}_m$ increased from 90 to 800 keV. The energy spectrum of the beam emerging from the monocrystalline foil consisted of two well separated peaks. For the low-energy peak, the R values normalized to equal emergent energy were close to those for polycrystalline foils; for the high-energy peak, which is due to channeled ions, R was distinctly lower (at 100 keV, $R_{chann} = 0.335$, $R_{normal} = 0.460$).

158th American Chemical Society Meeting

New York, 8—12 September 1969

A SURVEY OF SINGLE-PARTICLE AND COLLECTIVE STATES IN THE ACTINIDES BY USE OF TRANSFER REACTIONS

A. M. Friedman,* J. R. Erskine, T. H. Braid, and R. R. Chasman*

Abstracts of Papers, NUCL-77

The levels of many odd-A actinide nuclei have been studied with (d,p), (d,t), and (^{3}He, ^{4}He) reactions. We have used targets of ^{230}Th, ^{232}Th, ^{234}U, ^{236}U, ^{238}U, ^{240}Pu, ^{242}Pu, ^{244}Cm, ^{246}Cm, and ^{248}Cm. The mechanism of these reactions is especially suitable for exciting single-particle states. The nature of the angular-momentum selection rules is such that the cross sections leading to the population of various members of a rotational band are simply related to the wave function of that state and provide a test of the wave function and a relatively unambiguous method for the identification of many of these states. With the aid of this technique we have been able to observe single-particle levels up to 1.5 MeV in most odd-A nuclei, and their properties are in qualitative agreement with theory. We have been able to chart their energies, level spacings, and ordering in isotopes of Th, U, Pu, and Cm. In many cases, states not predicted by the Nilsson model appear at excitations of 0.7—1 MeV and are presumably vibrational; however, the cross sections for many of these appear larger than one would expect from their single-particle components.

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*Chemistry Division.

International Conference on Mass Spectrometry

Kyoto, Japan, 8—12 September 1969

MASS-SPECTROMETRIC STUDIES OF EFFECTS CONNECTED WITH MeV ION CHANNELING IN METAL MONOCRYSTALS

M. Kaminsky

When energetic ions penetrate through a monocrystalline solid, their trajectories can under certain conditions be influenced by the regular arrangment of the lattice atoms. In particular, they may be guided through the spaces between planes (planar channeling) or along channels formed by parallel rows of atoms along certain crystallographic directions (axial channeling). In such cases, the impact parameters of successive collisions can become correlated and their distribution is not random as in the case of ion penetration through amorphous solids. Such directional effects ("channeling" effects) have been observed in various atomic and nuclear phenomena. The experimental and theoretical studies of some of these processes (e.g., ion ranges, ion reflection, energy loss, x-ray emission, radiation damage, and nuclear reactions) have been reviewed recently.[1]

The experiments to be described here are part of a program to determine the influence of channeling on the yields of sputtering,[2] secondary-electron emission,[3] and secondary-ion

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[1] S. Datz, C. Erginsoy, G. Leibfried, and H. O. Lutz, Ann. Rev. Nucl. Sci. 17, 129 (1967).

[2] M. Kaminsky, Adv. Mass Spectrometry 3, 69 (1964—1966); Phys. Rev. 126, 1267 (1962).

[3] M. Kaminsky et al., Proceedings of the 25th Annual Conference on Physical Electronics, M.I.T. (1965), p. 212; Proceedings of the 26th Annual Conference on Physical Electronics, M.I.T. (1966), p. 331; Bull. Am. Phys. Soc. 10, 1105 (1965); Argonne National Laboratory Report ANL-7354 (1967), p. 125.

emission,[4] as well as on the energy-loss[5] and charge-transfer processes[6] for light ions (Z = 1 or 2) impinging on metal monocrystals with energies ranging from 0.1 to 4.0 MeV. In the present studies the total yields of sputtering, secondary-electron emission, and secondary-ion emission in dependence on the crystallographic orientation of monocrystalline Cu and Ag targets were measured with light incident ions (H^+, D^+) in the 0.1—4.0-MeV range. The direction of the incident ion was held parallel (to within 0.1°) to the [111], [100], or [110] direction of the Cu and Ag monocrystals, and they had an angular spread of less than 0.01°. The target region was held under ultra-high vacuum (3×10^{-9} Torr—1×10^{-8} Torr) to avoid surface contamination. The structural quality of the monocrystals was checked by Laue diagrams taken in back reflection. The experimental arrangement used to measure the secondary-particle yields has been described previously.[2—4]

Figure 26 illustrates some typical yield data obtained for the case of protons incident normal to different crystallographic planes of silver monocrystals. One notices that the secondary-particle yields decrease in the order [111] > [100] > [110], which is the same order in which the transparency of the lattice along the respective directions becomes larger. To determine to what degree the production mechanism of internal secondary particles contributes to the observed orientation dependence of the yields, the characteristic energy loss of ions along the low-index directions was measured.

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[4] M. Kaminsky *et al.*, Proceedings of the 26th Annual Conference on Physical Electronics, M.I.T. (1966), p. 316; Argonne National Laboratory Report ANL-7246 (1966), p. 124.

[5] M. Kaminsky, Bull. Am. Phys. Soc. **12**, 635 (1967); Argonne National Laboratory Report ANL-7354 (1967), p. 126 and ANL-7481 (1968), p. 148; Bull. Am. Phys. Soc. **13**, 1406 (1968).

[6] M. Kaminsky, Bull. Am. Phys. Soc. **13**, 1405 (1968).

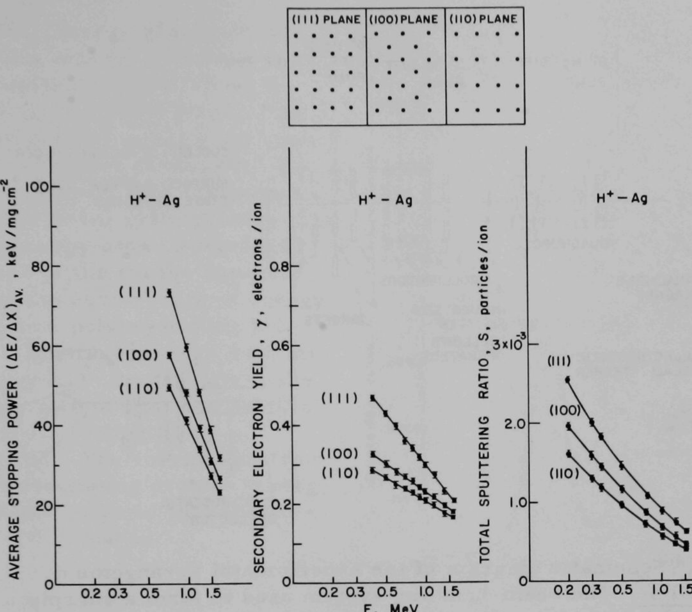

Fig. 26. Values for the mean stopping power (the average energy loss per unit path length), the total secondary-electron yield γ, and the total sputtering yield S for protons incident with energy E and penetrating through silver monocrystalline foils with their surfaces parallel to the indicated crystal planes.

The energy loss of protons penetrating through thin monocrystalline silver and copper foils of different but well-defined crystallographic orientations was measured for $E_p = 0.75—1.75$ MeV for various angles of incidence. Over twice the area struck by the beam, each foil thickness varied by $\lesssim 3\%$. The angular spread of the incident proton beam was $< 0.01^{\circ}$ and the angle of incidence was defined to $< 0.1^{\circ}$. The emerging protons were collimated before being analyzed with a surface-barrier solid-state detector (as shown in the upper half of Fig. 27). For protons incident within 0.2° of the [111], [100], or [110] direction, the emergent-particle spectrum

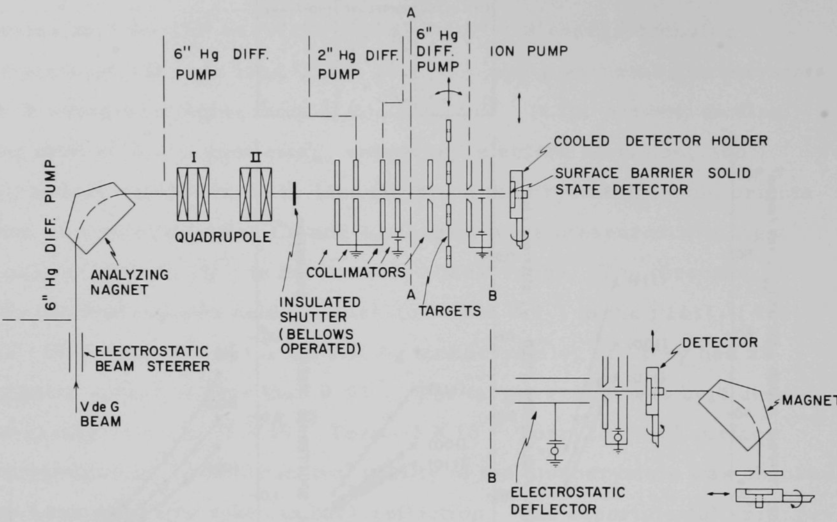

Fig. 27. Schematic diagram of the experimental arrangement. Upper left: The beam-handling system used to form a sharply directed beam of the selected species of ions. Upper right: Detector system to measure the characteristic energy losses of ions in metal monocrystals. Lower right: System used to determine the distribution of charge states of ions penetrating through polycrystalline or monocrystalline metal foils.

consisted of two well-separated peaks (as shown, for example, in Fig. 28). The mean energy $\overline{E}_N$ of the low-energy peak corresponded to the normal energy loss observed for polycrystalline targets of the same material and the same thickness, while the mean energy $\overline{E}_c$ of the high-energy peak reflects the reduced loss rate for channeled particles. The observation that the energy-loss rate of channeled particles is approximately half that of unchanneled particles supports Lindhard's equipartition rule. Furthermore, the energy-loss rate of channeled particles decreases in the order [111] > [100] > [110], which is the same order observed for the yield values (Fig. 26). These results suggest that the production mechanism of internal secondary particles has a strong influence on the observed orientation dependence of the yield values.

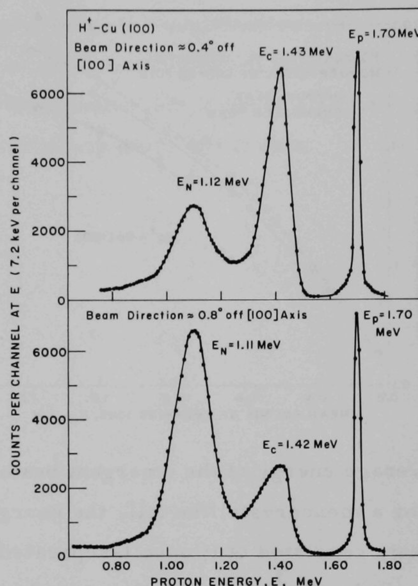

Fig. 28. Energy spectrum of protons emerging from a monocrystalline copper foil whose surface is a (100) plane. The incoming beam makes an angle of 0.4° (upper curve) or 0.8° (lower curve) with the perpendicular to the (100) planes. The low-energy peak (labeled E_N) comes at the energy expected from the normal rate of energy loss in a polycrystalline target. The high-energy peak (at energy E_c) corresponds to the lower rate of energy loss by a proton traveling along a channel. The energy spectrum of the incoming protons (energy E_p) was obtained with the target foil removed.

Further insight into the processes that slow down an ion penetrating a solid was gained by studying the charge-transfer processes by which energetic particles may capture or lose electrons as they interact with the lattice atoms. In these experiments, Cu(100) foils and polycrystalline Cu foils were bombarded by $^3He^+$ ions in the energy range 0.6—2.0 MeV, with a highly collimated incident beam (spread <0.01°). The beam direction was ~0.1° off the [100] axes of the Cu(100) foils and was perpendicular to the surface of the polycrystalline targets. Over four times the area actually struck by the beam, each foil thickness varied by $\lesssim$3%. For the foil thicknesses used (0.8—2.0 mg/cm^2), only equilibrium charge distributions were observed. The emerging ions were analyzed magnetically according to their charges, and the ratio R(emergent beam) = $^3He^{++}/^3He^+$ was measured (lower half of Fig. 28) for different primary $^3He^+$ energies under ultra-high vacuum conditions. For example, for polycrystalline Cu, R varied from ~0.38 to 35 as the

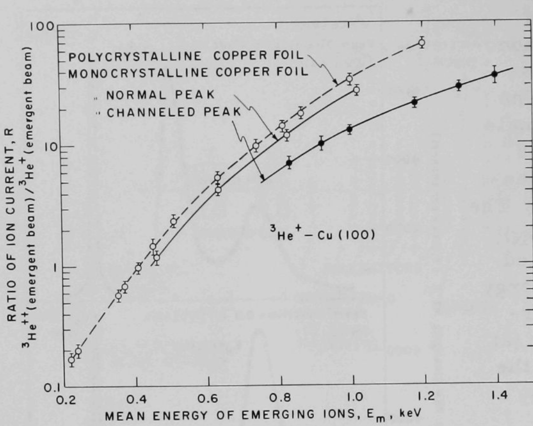

Fig. 29. The ratio of doubly-ionized to singly-ionized helium-3 ions emerging from copper foils bombarded with singly-charged helium-3 ions incident perpendicular to the plane of the foil. The curves show how this ratio depends on the mean energy of the ions as they emerge from the foils. The dashed curve is for a polycrystalline foil. The solid curves are for unchanneled and channeled ions emerging from a monocrystalline foil whose surface is parallel to the (100) planes. At approximately 412 keV the cross sections for electron loss and electron capture for the reaction $^3He^{++} \longleftrightarrow {}^3He^+$ are equal.

average energy of the emergent beam increased from 0.3 to 1 MeV. For a monocrystalline foil, the energy spectrum of the emergent beam consisted of two well-separated peaks, and the charge of the emerging He^3 ions was determined both for ions in the high-energy peak and for those in the low-energy peak. For the low-energy peak, the ratio R of doubly- to singly-charged ions emerging at each energy was close to the ratio observed with a polycrystalline foil (as seen in Fig. 29); but the ratio R was significantly lower for the high-energy peak characteristic of channeled ions. Thus, ions traversing and escaping through regions of lower electron density (e.g., the centers of lattice channels) have a lower probability of losing electrons than do those traveling at random in the crystal.

One promising application of the charge-transfer study is to the design of foils to add or remove electrons as ions pass through them. In a tandem Van de Graaff accelerator, for example, thin monocrystalline "stripper" or "adder" foils would be advantageous since the channeled ions emerging from them are much more concentrated in the forward direction than are those emerging from polycrystalline foils or from gaseous charge-exchange targets.

I most gratefully acknowledge the contributions of Gordon Goodwin, whose assistance in the assembly of the equipment, in its operation, and in data taking was invaluable. I would also like to thank Mr. P. Dusza for his help in taking some of the data.

Third International Conference on High Energy Physics and Nuclear Structure

Columbia University, 8—12 September 1969

PARITY MIXING IN ^{16}O

E. L. Sprenkel-Segel, R. E. Segel, and R. H. Siemssen

It was pointed out about ten years ago[1] that a very sensitive way to search for parity nonconservation in nuclei is to look for an alpha branch from the 8.88-MeV state in ^{16}O in the delayed alpha spectrum following the β decay of ^{16}N. Figure 30 shows the energy level diagram. Previous attempts[2—4] to detect this decay mode found $\Gamma_{\alpha} \leq 10^{-8}$ eV, which implies an upper limit $F^2 \lesssim 2 \times 10^{-12}$ for the intensity of the opposite-parity component in the wave function. We have repeated this experiment, using new techniques which have improved the sensitivity by at least an order of magnitude.

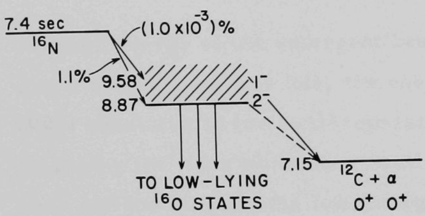

Fig. 30. Energy level diagram.

The previous experiments have been limited by counting statistics. The 400-keV-wide 9.58-MeV state, which decays solely by alpha emission, is fed by a 10^{-5} branch, and the alphas from the 8.88-MeV state lie on the low-energy tail of the broad group. Thus, the search is for a sharp peak superimposed on a continuum. Two

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[1] R. Segel, J. Olness, and E. Sprenkel, Phil. Mag. 6, 163 (1961).

[2] R. Segel, J. Olness, and E. Sprenkel, Phys. Rev. 123, 1382 (1961).

[3] P. F. Donovan, D. E. Alburger, and D. H. Wilkinson, Proceedings of the Rutherford Jubilee Conference, Manchester, 1961, edited by J. B. Birks (Heywood and Co., London, 1961), p. 827.

[4] W. Kaufmann and H. Waffler, Nucl. Phys. 24, 62 (1961).

major improvements in technique have led to a much higher counting rate. First, the ^{16}N was separated out from the target material, thus greatly increasing the specific activity of the source. Since the total source thickness is limited by the requirements of good alpha-energy resolution (and therefore small loss of alpha energy) increasing the specific activity increases the counting rate. The second major innovation was that the detection of electrons was prevented by sweeping them out with a magnetic field. There are 10^5 electrons produced for every alpha particle in the decay of ^{16}N, and these electrons would smear the energy resolution of the detector if the counting rate gets too high. However, by almost completely eliminating these betas it was possible to take full advantage of the higher yield occasioned by the increased specific activity.

The ^{16}N was formed in the ^{19}F(n, α) reaction, $Q = -1.50$ MeV, produced by fast neutrons from the Argonne CP-5 research reactor. The ^{16}N recoils emerged from thin layers of CaF coated on aluminum plates, and were thermalized in a carrier gas. A trace of NO in the nitrogen carrier was found to pick up a substantial fraction of the active nitrogen. After being carried about 50 ft, the ^{16}NO was frozen out on a surface viewed by a silicon detector about 1.5 cm away. The source and detector were in a 50 kG field generated by a superconducting magnet.

The running procedure was to flow gas for 10 sec and then count for 10 sec with the chamber evacuated. Data were taken over a 10-day period. Figure 31 shows the spectrum obtained by combining the data from the many individual runs taken during this period. A total of about 10^6 alpha particles are in the spectrum—at least 20 times the yield of any of the previous experiments.[2–4] An arrow points to the expected position of the parity-violating group and, indeed, there is a small bump in the spectrum at the right place.

The broad group was fitted with a single-level Breit-Wigner formula, suitably modified for extranuclear effects and for

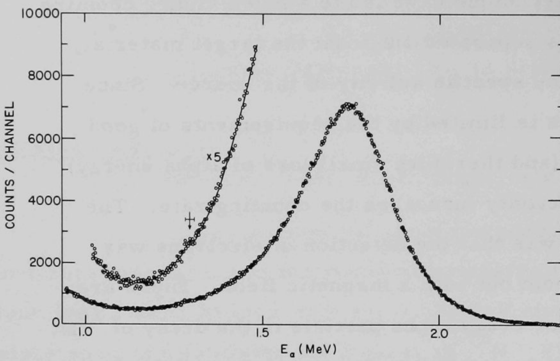

Fig. 31. Delayed alpha-particle spectrum following the beta decay of ^{16}N. The rise at low pulse heights is due to electrons. The arrow points to the expected position of the parity-violating group.

transitions directly through the continuum. In the difference spectrum obtained by subtracting off the broad groups, a sharp peak with a magnitude of $2\frac{1}{2}$ standard deviations was found at 1.287 ± 0.015 MeV—in good agreement with the expected position of 1.295 ± 0.010 MeV. No other peak of comparable statistical significance was found in the difference spectrum.

It was not possible to further improve the counting statistics or to check for systematic error because of a scheduled 1-yr shutdown of the reactor. Until the results can be checked further, they must be considered as preliminary.

If the branching ratio to the 9.58-MeV state is taken to be 1×10^{-5} and the lifetime of the 8.88-MeV state to be 1.5×10^{-13} sec, the tentative effect found here corresponds to an alpha width of 1×10^{-9} eV which, in turn, corresponds to a parity impurity $F^2 \approx 2 \times 10^{-13}$. An impurity of this magnitude is consistent with the parity-violating component to be expected in the nucleon-nucleon potential on the basis of the conserved-vector-current theory of the weak interactions, although the theoretical uncertainties are quite large.

III. ABSTRACTS OF PAPERS ACCEPTED FOR PUBLICATION

OBSERVATION OF THE $(g_{9/2})^2$ MULTIPLET IN Nb^{90} VIA THE (He^3, t) REACTION

R. C. Bearse, J. R. Comfort, J. P. Schiffer, M. M. Stautberg, and J. C. Stoltzfus

Phys. Rev. Letters (13 October 1969)

A report on this work, presented as a Research Highlight, appears on p. 11.

(d,p) AND (d,t) REACTION STUDIES OF THE ACTINIDE ELEMENTS. I. U^{235}

T. H. Braid, R. R. Chasman,* J. R. Erskine, and A. M. Friedman*

Phys. Rev.

Levels of the nucleus U^{235}, populated in the reactions $U^{234}(d,p)U^{235}$ and $U^{236}(d,t)U^{235}$ induced by 12-MeV deuterons from the Argonne tandem, were analyzed with a magnetic spectrograph. Most of the observed levels were identified as members of rotational bands built on the single-particle states of a deformed central field. The level assignments were made on the basis of relative populations of presumed members of each rotational band, ratios of the cross sections at 90° and 140°, and (d,p)/(d,t) cross-section ratios. Pairing effects were calculated for the observed spectrum and a single-particle scheme was extracted from the data. This single-particle scheme was compared with the calculations of Nilsson and Rost. Levels not predicted on the basis of the single-particle models were observed at excitations as low as 700 keV. Some of these levels, presumably vibrational excitations, were found to have cross sections comparable to those of single-particle states.

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*Chemistry Division.

EXTENSION OF THE OPTICAL MODEL, AND ITS APPLICATION TO THE ELASTIC SCATTERING OF ^{16}O BY ^{16}O NUCLEI

R. A. Chatwin,* J. S. Eck,* D. Robson,* and A. Richter
Phys. Rev.

The absorptive part of the optical potential is considered as a function of conserved quantum numbers such as the total angular momentum J. This investigation results in the introduction of a smooth cutoff in the strength of the absorptive potential as J gets larger than a certain critical value. This value is typical of nonelastic channels, and the cutoff reflects poor matching between the angular momenta in the elastic channel and those in the nonelastic channels. Brief consideration is also given to other conserved or approximately conserved quantum numbers such as isobaric spin and parity. The standard optical potential is modified to include an angular-momentum dependence with a suitable cutoff, and is applied to the elastic scattering of ^{16}O by ^{16}O nuclei. In the energy range 15—36 MeV(c.m.) such an extended optical model gives a good description of all the gross features of the ^{16}O-^{16}O data. A repulsive core in the ^{16}O-^{16}O potential has been considered, but no definite evidence for it is found in the present analysis.

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*Florida State University, Tallahassee, Florida.

HIGH-RESOLUTION PHOTOIONIZATION STUDY OF THE H_2 MOLECULE NEAR THRESHOLD

W. A. Chupka and J. Berkowitz
J. Chem. Phys. (15 November 1969)

Relative photoionization and absorption cross sections of H_2 (ordinary and para) have been measured from 745—810 Å at 300°K and 78°K, with a resolution width of 0.04 Å. The photoionization data show the presence of extensive structure due to autoionization of vibrationally excited Rydberg states. Analysis of the data on the D-X(6,0) band in the region of the ionization threshold leads to the conclusion that the ionization potential of H_2 lies between 124 418.2 cm^{-1} and 124 393.5 cm^{-1} and is probably very near the former value. Analysis of the data on the B''-X(4,0) band requires either that the ionization potential lies below 124 407.2 cm^{-1} (which is rather unlikely) or that autoionization of the R(2) and R(3) lines occurs in violation of one of the autoionization selection rules proposed by Beutler and Jünger. Some Rydberg states that lie just below their ionization limits and do not autoionize spontaneously can be made to ionize in

weak electric fields and by collision with unexcited H_2 molecules. Direct ionization of H_2 (J=0) appears to begin about 23 cm^{-1} below the expected threshold, probably as a result of collisional ionization of Rydberg states lying just below the ionization threshold. A series of peaks appearing in a short region immediately above threshold apparently coincides with a series which Herzberg has observed in absorption and identified as the Rydberg series converging to the rotationally excited K=2 state of the H_2^+ ion. The autoionization of these Rydberg states must occur by conversion of rotational to electronic energy. An intensity anomaly of this series is ascribed to channel interaction with a vibrationally excited Rydberg state. A large number of the autoionization peaks have been identified in the spectrum of para hydrogen at $78^\circ K$. By comparison of the absorption cross section with the photoionization cross section, it was found that all states that can autoionize with $\Delta v = 1$ are strongly autoionized ($\sim$40—100%) while the autoionization probabilities of states that autoionize with $\Delta v > 1$ vary widely. The dominance of autoionization with $\Delta v = 1$ over predissociation extends to the very highest Rydberg states and leads to the absence of observable thresholds for formation of vibrationally excited H_2^+ ions. Some peaks that autoionize with $\Delta v = 1$ have widths larger than the instrumental width and the autoionization rates have been estimated. They are in fair quantitative agreement with recent calculations of Nielsen and Berry. The widths decrease rapidly with principal quantum number as Bardsley predicts. The autoionization rate decreases by about a factor of ten or more when the Δv of the transition changes from 1 to 2. For larger values of Δv, the autoionization rate appears to decrease still more but not necessarily as a monatonic function of Δv.

THE GROUND STATE OF HOMOGENEOUS NUCLEAR MATTER AND THE FOUNDATION OF THE NUCLEAR SHELL MODEL

F. Coester

Quantum Fluids and Nuclear Matter (Gordon and Breach, Science Publishers, New York, 1969)

Introduction; states of low-density fermion systems; stationary states of homogeneous nuclear matter; solutions for soft potentials; solutions for hard potentials; the ground state of a closed-shell nucleus; the shell-model problem.

FOUR-HOLE-LINE DIAGRAMS IN NUCLEAR MATTER

B. D. Day

Phys. Rev. (20 November 1969)

The Brueckner-Goldstone diagrams with four independent hole lines, which give the third term in the expansion for the ground-state energy of infinite nuclear matter, are enumerated. These diagrams are grouped in a natural way into 16 distinct classes. Only one of these classes (the four-body clusters) involves the solution of a four-body equation. Six classes require the solution of the three-body Bethe-Faddeev equations, and nine classes can be evaluated in terms of two-body matrix elements alone. Exact formal expressions are given for the contribution to the energy from each class of diagrams. In these expressions, all exchange diagrams are included, and all energy denominators are clearly defined. Numerical estimates are made for each class of diagrams, assuming the two-body interaction to be the Reid soft-core potential. The sum of all contributions is attractive and is about 0.6—1.6 MeV. Most of the uncertainty in this result is caused by omission of the tensor force in certain diagrams. The implications of these results for the convergence of the energy expansion are discussed.

PRESYMMETRY. II

H. Ekstein

Phys. Rev. (25 August 1969)

The association between laboratory procedures and self-adjoint operators (observables), usually implicit and allusive, is made explicit by the introduction of two collections of nonmathematical objects; the observation procedures and the state-preparing procedures. By a process of idealization and extrapolation from empirical facts, these two collections are turned into mathematical sets ("hardware spaces") with the structure of a star algebra $\mathcal{O}$ and a convex linear set $\mathcal{S}$, respectively. There is a many-one mapping from $\mathcal{O}$ into the space $\mathfrak{A}$ of observables (the operators on Hilbert space), and physical laws or solutions of equations of motion are embodied in the mapping Φ: $\mathcal{O} \to \mathfrak{A}$. Certain material motions of observation instruments and state-preparing instruments induce automorphisms of the hardware spaces but, in general, not automorphisms of $\mathfrak{A}$. An extension of space-time invariance theory to accelerations

$$[\underset{\sim}{x} \to \underset{\sim}{x} + \sum_{2}^{\infty} (n!)^{-1} \underset{\sim}{r}_n t^n],$$

to external symmetry-breaking fields, and to subsystems under the influence of other subsystems becomes possible. The main results of this paper are a derivation of Newton's second law and of the gravitational equivalence principle for nonrelativistic quantum mechanics from invariance and causality principles.

STUDY OF THE $^{39}K(d,t)^{38}K$ REACTION AT E_d = 23 MeV

H. T. Fortune, N. G. Puttaswamy, and J. L. Yntema

Phys. Rev. (20 September 1969)

The $^{39}K(d,t)^{38}K$ reaction has been utilized to study states in ^{38}K below an excitation energy of 5 MeV. Spectroscopic factors have been extracted by comparing the data with distorted-wave calculations. For states for which both ℓ = 0 and ℓ = 2 transitions are allowed, attempts have been made to extract relative admixtures. Two positive-parity states, not previously reported in neutron-pickup experiments, have been observed at E_x = 3.44 and 3.99 MeV. Two weak negative-parity states have been observed at E_x = 2.64 MeV (ℓ = 1) and 4.66 MeV (ℓ = 3), indicating the admixture of core-excited configurations in the ground state-wave function of ^{39}K.

TEST OF THE BARSHAY-TEMMER THEOREM FOR THE REACTION $^{10}B + \alpha \rightarrow {}^{7}Li + {}^{7}Be$

H. T. Fortune, A. Richter, and B. Zeidman

Phys. Letters B (29 September 1969)

The Barshay-Temmer theorem has been tested via the reactions $^{10}B(\alpha, {}^{7}Li_{g.s.})^{7}Be_{g.s.}$ and $^{10}B(\alpha, {}^{7}Be_{g.s.})^{7}Li_{g.s.}$ at E_α = 46 MeV. In order to minimize experimental uncertainties, angular distributions for both reactions were measured simultaneously; the symmetry required by the theorem was shown by the fact that the ratio between the intensities of the outgoing particles at a fixed angle is unity within the experimental uncertainties. This implies an extreme similarity of the wave functions of the ground-state isobaric doublet ^{7}Li-^{7}Be and provides a simple test of the charge independence of nuclear forces.

DISTORTED-WAVE ANALYSIS OF THE $^{11}B(d,p)$ REACTION LEADING TO THE LOWEST UNBOUND LEVEL IN ^{12}B

H. T. Fortune and C. M. Vincent

Phys. Rev. (20 September 1969)

The 3.39-MeV state of ^{12}B is 20 keV above the threshold for neutron decay, and has been seen both in $^{11}B(d,p)^{12}B$ and in $^{11}B(n,n)^{11}B$. We present an analysis of $^{11}B(d,p)^{12}B$ by a new technique, and combine the stripping and elastic-scattering data to obtain the spin and parity of the state in question. Our best fit to the (d,p) angular distribution is obtained for the assumption of $\ell = 2$ angular momentum transfer. Furthermore, this ℓ value is the only one that gives a spectroscopic factor consistent with the neutron width measured in $^{11}B + n$. We conclude that the state probably has spin-parity 3^-, in contradiction to earlier analyses.

ENERGY LEVELS IN ^{33}P

G. Hardie, R. E. Holland, L. Meyer-Schützmeister, F. T. Kuchnir, and H. Ohnuma

Nucl. Phys. (1969)

The energies of many levels in ^{33}P were obtained by a magnetic-spectrograph analysis of the protons from the $^{30}Si(\alpha,p)^{33}P$ reaction. Proton-gamma angular correlations were studied in the same reaction. Several gamma-decay branching ratios were determined. It was found that the 3.50-MeV state has a spin of $\frac{3}{2}$ or $\frac{5}{2}$, and the 3.63-MeV state has a spin of $\frac{7}{2}$. It is argued that the parity of the 3.63-MeV state is positive and that $\frac{7}{2}^-$ is the most likely assignment for the 4.23-MeV state. Mixing ratios of several transitions were also obtained.

NUCLEAR MODELS

David R. Inglis

Phys. Today (June 1969)

The spherical shell, the deformed shell, "infinite nuclear matter," the droplet—each of these models provides a simplification that can be useful, in appropriate circumstances, to the study of the nucleus.

THEORY OF NUCLEAR LEVEL DENSITY FOR PERIODIC INDEPENDENT-PARTICLE ENERGY-LEVEL SCHEMES

Peter B. Kahn* and Norbert Rosenzweig

Phys. Rev. (20 November 1969)

Accurate and perspicuous formulas are derived for the density of states of a degenerate system of any number of types of Fermions moving in arbitrary periodic single-particle energy-level schemes. The results are of the standard form with the modification that the excitation energy is to be replaced by an "effective energy." The effective energy contains an additive correction which depends explicitly on the structure and ground-state occupation of the periodic level sequences. The spin-dependent level-density formula for two kinds of particles should be useful in the correlation of observed nuclear level densities with shell-model level sequences. The present work generalizes, unifies, and simplifies earlier treatments of related problems.

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MÖSSBAUER ISOMER SHIFT IN ^{243}Am

G. M. Kalvius,* S. L. Ruby, B. D. Dunlap,* G. K. Shenoy,* D. Cohen,† and M. B. Brodsky‡

Phys. Letters (21 July 1969)

We have observed the nuclear γ-ray resonance of the 83.9-keV level in ^{243}Am. The measured isomer shift between AmO_2 and AmF_3 has been used to calculate $\delta\langle r^2\rangle/\langle r^2\rangle$ to be $-(9 \pm 3) \times 10^{-4}$. The nuclear parameters are compared with those of ^{237}Np.

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†Chemistry Division.

‡Metallurgy Division.

POLARIZATION OF CHANNELED PARTICLES

M. Kaminsky

Phys. Rev. Letters (13 October 1969)

A report on this work, presented as a Research Highlight, appears on p. 24.

POLARIZATION AND DIFFERENTIAL CROSS SECTION FOR NEUTRONS SCATTERED FROM ^{12}C

R. O. Lane, R. D. Koshel,* and J. E. Monahan

Phys. Rev.

The polarization $P(\theta)$ and differential cross section $\sigma(\theta)$ for the scattering of neutrons of $0.1 \leq E_n \leq 2.0$ MeV from ^{12}C have been measured at five or nine angles. $P(\theta)$ contains a slowly varying $\sin\theta$ term and is dominated by a negative $\sin 2\theta$ term which grows in strongly with energy so that $P(120^\circ)$ reaches as much as 40% at the higher energies. The experimental values of $\sigma(\theta)$ and $P(\theta)$ are simultaneously described reasonably well over this energy range in terms of a two-level R-function formalism. Background terms are estimated by use of a square-well interaction potential.

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SHELL-MODEL MATRIX ELEMENTS FROM A REALISTIC POTENTIAL

R. D. Lawson and J. M. Soper*

Nucl. Phys. (1969)

We present a new method of calculating the effective matrix elements of a "realistic" two-body interaction. We assume that the unperturbed energies of the single-particle states are those of an harmonic oscillator. For two particles outside an inert core, the problem can in some instances be solved exactly; in other cases, it is necessary to approximate the Pauli principle (in a way that is later shown to be justified). The theory is applied to ^6He, and for interaction energies involving relative s-state motion, our matrix

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elements are about 20% more attractive than those computed by use of the bare G matrix. Since the G-matrix calculations assume free-particle energies for states outside the model space, this difference gives some measure of the sensitivity of the computed T=1 matrix elements to assumptions about the single-particle energies used in intermediate states.

LIFETIME OF THE 11-keV LEVEL IN Cs^{134}

F. J. Lynch and L. E. Glendenin*

Phys. Rev. (20 October 1969)

The mean life of the 11-keV level following the decay of Cs^{134m} has been measured by a delayed-coincidence technique and found to be 69 ± 1 nsec. An indirect measurement of the total-internal-conversion coefficient for this transition (α = 105) agrees closely with the theoretical value for a pure M1 transition. This implies that the mean life for radiative decay is τ_0 = 7314 nsec. This is about 1.8 times the radiative mean life calculated with the odd-group model with the aid of the magnetic moments of neighboring nuclei.

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THE REACTION MATRIX IN NUCLEAR SHELL THEORY

M. H. Macfarlane

Proceedings of the International School of Physics "Enrico Fermi," Course XL: Nuclear Structure and Nuclear Reactions (Academic Press, New York, 1969)

Introduction; the assumptions and aims of nuclear shell theory; the single-particle potential and the model space of shell theory; equations for the effective interaction; separation of core and valence energies; the reaction matrix as effective interaction; core-excitation in two-particle shell-model systems; deformed states and state dependence of the effective interaction in O^{18} and F^{18}; the many-particle shell model; phenomenological shell-model interactions; phenomenological study of deformed states in O^{18} and F^{18}—the anatomy of a forced fit; moments and transition rates; and future prospects for nuclear shell theory.

$Ge^{73}(n,\gamma)Ge^{74}$ GAMMA-RAY SPECTRUM AND ENERGY LEVELS OF Ge^{74}

A. P. Magruder and R. K. Smither

Phys. Rev. (20 July 1969)

The γ-ray spectra resulting from thermal-neutron capture in targets of natural germanium and enriched Ge^{73} were measured with a Ge(Li) detector. The energies and intensities of 85 gamma rays in the energy range 0.20—3.00 MeV and 47 gamma rays in the range 6.1—9.6 MeV were identified with the reaction $Ge^{73}(n,\gamma)Ge^{74}$. The γ-ray spectrum was used to suggest four new levels, and place limits on the spins and parities of three other levels. Errors in the γ-ray energy values were reduced to less than 3 keV in all cases, and to less than 1 keV for many. On the basis of this experiment and other information, the energy levels identified below 3 MeV were 0.0 (0^+), 596.3 (2^+), 1204.9 (2^+), 1466.2 (4^+), [1486 (0^+)], [1697.7], 1699.9 ($3^\pm$,4^+), 2168.3 ($3^\pm$,4^+), 2200.2 (2^+), 2539.3 (3^-), 2574.1, 2672.4, [2695.8], 2699.1, 2833.2, 2929.2, 2939.7, and 2978.1 keV, where the levels in brackets were not fed directly from the capture state. The level energies were determined to within 1 keV. The energy of the capture state in the compound nucleus ($Ge^{73}+n$) was found to be 10 203.1 $\pm$ 0.9 keV.

STUDY OF THE $Al^{27}(He^3,p)Si^{29}$ AND $Al^{27}(He^3,p\gamma)Si^{29}$ REACTIONS

L. Meyer-Schützmeister, D. S. Gemmell, R. E. Holland, F. T. Kuchnir, H. Ohnuma, and N. G. Puttaswamy

Phys. Rev. (20 November 1969)

The levels of Si^{29} have been studied by measuring angular distributions of the $Al^{27}(He^3,p)Si^{29}$ reaction. A few states, in particular the level at 8.310 MeV (the analog of the Al^{29} ground state), were strongly excited with an orbital-angular-momentum transfer L = 0 leading to states with $J = \frac{3}{2}^+$, $\frac{5}{2}^+$, and possibly $\frac{7}{2}^+$. The γ decay of some of these levels has been studied by p-γ coincidences. They all showed a very similar γ decay, namely, a preference to decay to those few positive-parity states that are also strongly populated in the (He^3, p) reaction. From the radiative decay of the 8.310-MeV level and other evidence, we conclude that the $\frac{5}{2}^+$ state at 4.906 MeV contains the major portion of the antianalog strength. The coincidence data also contained events from $Al^{27}(He^3,d\gamma)Si^{28}$. Analysis of these results showed that they were consistent with previous measurements.

ISOMER SHIFTS AND ELECTRONIC STRUCTURE OF PdSb ALLOYS

H. Montgomery* and S. L. Ruby

Phys. Rev. (1969)

Sb^{121} isomer shifts are presented for α-phase PdSb alloys and for the compounds PdSb and $PdSb_2$. The results are compared with similar data for PdSn and PdAu, and it is shown that they are compatible with a model in which the solute atoms are almost perfectly screened by conduction electrons.

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COULOMB ENERGIES—AN ANOMALY IN NUCLEAR MATTER RADII

J. A. Nolen, Jr., and J. P. Schiffer

Phys. Letters (23 June 1969)

Nuclear matter radii were calculated from measured Coulomb energy differences and charge radii. The Coulomb energy differences were taken between nuclear states that are members of an isobaric-spin multiplet. A significant anomaly in the radius of the excess nucleons was found. In the mirror pair ^{41}Ca-^{41}Sc, for instance, the known charge radius of the ^{40}Ca core was used to extract the rms radius for the 41st nucleon. This radius is virtually the same as that of the ^{40}Ca core, whereas any simple potential model would predict the $1f_{7/2}$ orbit to be ~20% larger than the average radius of the lower orbits. This qualitative effect is present in other mirror nuclei, and is also a feature of Coulomb energy differences from isobaric-spin analog states in heavier nuclei, for which the neutron excess is larger.

HYPERFINE ANOMALY IN ^{193}Ir BY THE MÖSSBAUER EFFECT, AND ITS APPLICATION TO DETERMINATION OF THE ORBITAL PART OF HYPERFINE FIELDS

G. J. Perlow, W. Henning, D. Olson, and G. L. Goodman*

Phys. Rev. Letters (29 September 1969)

A 7% hyperfine anomaly is found in Mössbauer measurements of the 73-keV transition in ^{193}Ir. A 2% difference

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is found between the anomalies in antiferromagnetic IrF_6 and ferromagnetic Ir-Fe alloy. The difference is ascribed to orbital contributions which differ for the two iridium environments. By using known details of IrF_6 we find the orbital field in the Ir-Fe to be $H_\ell = +335 \pm 200$ kOe.

A DIELECTRIC FLUID DROP IN AN ELECTRIC FIELD

C. E. Rosenkilde

Proc. Roy. Soc. (London) (1969)

In this paper an appropriate extension of the virial method developed by Chandrasekhar is used to systematically re-examine the equilibrium and stability of an incompressible dielectric fluid drop situated in a uniform electric field. The equilibrium shapes are initially assumed to be ellipsoidal; and it is shown that only prolate spheroids elongated in the direction of the applied field are compatible with the moment equations of lowest order. The relation between the equilibrium elongation a/b and the dimensionless parameter $x = FR^{1/2}/T^{1/2}$, where F is the applied field, $R = (ab^2)^{1/3}$, and T is the surface tension, is obtained for every dielectric permeability ϵ. This relation is monotonic if $\epsilon \leq 20.801$; but if $20.801 < \epsilon < \infty$, there exist as many as three different equilibrium elongations (configurations) for some values of x less than 2.0966. Conditions for the onset of instability are obtained from an examination of the characteristic frequencies of oscillation associated with second-harmonic deformations of the equilibrium configurations. Dielectrics having $\epsilon > 20.801$ exhibit instability while those having $\epsilon \leq 20.801$ do not. In the former case, where there are three different equilibrium configurations for the same value of x, only the middle one is unstable.

NUCLEAR GAMMA-RAY RESONANCE STUDY OF HYPERFINE INTERACTIONS IN ^{238}U

S. L. Ruby, G. M. Kalvius,* B. D. Dunlap,* G. K. Shenoy,* D. Cohen,† M. B. Brodsky,‡ and D. J. Lam‡

Phys. Rev. (10 August 1969)

Nuclear γ-ray resonance (the Mössbauer effect) has been observed in ^{238}U using the 44.7-keV transition from the first

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excited state (2^+) to the ground state (0^+). The γ rays were obtained from the α decay of ^{242}Pu. The source material (PuO_2) gave a single emission line having a width of about 40 mm/sec, which is roughly 1.5 times the natural linewidth. Absorption spectra were taken in the temperature region between 77 and 4.2°K using the following absorbers: UO_2, UC, UF_4, $(UO_2)(NO_3)_2 \cdot 6H_2O$, UO_3, UFe_2, and α-uranium metal. Several compounds showed partially resolved hyperfine spectra. In UO_2 the resonance line broadens by a factor of 2 when cooling from 77 to 4.2°K. By fitting a pure magnetic hyperfine spectrum to the widened line, a hyperfine field of 2700 ± 200 kOe was deduced, using $g(2^+) = g_R = 0.25$. The resonance in $(UO_2)(NO_3)_2 \cdot 6H_2O$ can be explained by a pure electric quadrupole interaction $e^2qQ = -6100 \pm 225$ MHz. The isomer shift between U^{4+} and U^{6+} compounds is smaller than 2 mm/sec, thus giving a limit for the relative change in nuclear charge radius, namely $|\delta\langle r^2\rangle/\langle r^2\rangle| \leqslant 10^{-5}$.

CHANGE IN NUCLEAR RADIUS UPON EXCITATION FOR ^{119}Sn, ^{121}Sb, ^{125}Te, $^{127,129}I$, AND ^{129}Xe FROM MÖSSBAUER ISOMER SHIFTS

S. L. Ruby and G. K. Shenoy*

Phys. Rev. (10 October 1969)

The ratio $\delta\langle R^2\rangle/\langle R^2\rangle$ for two nuclei can be obtained by comparing the measured isomer shifts for isoelectronic compounds of the two elements. Such a determination is fairly insensitive to the absolute value of the electron density at the nucleus. These ratios have been found sequentially for ^{119}Sn, ^{121}Sb, ^{125}Te, $^{127,129}I$, and ^{129}Xe. Taking $\delta\langle R^2\rangle/\langle R^2\rangle$ for ^{119}Sn to be 2.4×10^{-4}, absolute values of $\delta\langle R^2\rangle/\langle R^2\rangle$ for the remaining nuclei have been found. The values are -14.6×10^{-4}, 1.9×10^{-4}, -4.8×10^{-4}, 6.2×10^{-4}, and 0.55×10^{-4} for ^{121}Sb, ^{125}Te, ^{127}I, ^{129}I, and ^{129}Xe, respectively. These values overlap those obtained directly by our electron-density calibrations, done individually, although they are different in some cases from earlier determinations. These results also supply a consistent set of values for the isomer shift per 5p or 5s electron for all five elements.

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ON COULOMB ENERGIES, THE ANOMALOUS ISOTOPE SHIFT OF NUCLEAR RADII, AND CORE POLARIZATION BY THE NEUTRON EXCESS

J. P. Schiffer, J. A. Nolen, Jr., and N. Williams

Phys. Letters (23 June 1969)

Coulomb energy differences, obtained from isobaric analog states, were made the subject of a careful quantitative study in strings of isotopes with closed proton shells. The behavior of these energies with increasing neutron excess in Ca isotopes was found to differ qualitatively from that in the Ni or Sn isotopes. With measured values of charge radii, the Coulomb energy differences are used to deduce neutron radii and nuclear matter radii. It is concluded that the addition of $f_{7/2}$ neutrons in Ca does little to change the radius of the core of closed shells in ^{40}Ca while the addition of neutrons in Ni and Sn polarizes the core appreciably. The trend in neutron and proton radii is similar in each of the three series of isotopes.

LEVEL SCHEME OF ^{153}Sm BASED ON (n, γ), (n, e^-), AND β-DECAY EXPERIMENTS

R. K. Smither, E. Bieber, T. von Egidy,* W. Kaiser,* and K. Wien†

Phys. Rev. (20 November 1969)

The ^{152}Sm(n, γ)^{153}Sm spectrum was measured with the Argonne bent-crystal spectrometer and with a Ge(Li) detector at the in-pile facility at the Argonne CP-5 research reactor. The low-energy bent-crystal spectrum consisted of 251 gamma transitions associated with thermal-neutron capture in ^{152}Sm, with energies between 28 keV and 1041 keV. The gamma-ray intensities were normalized to the previously established intensity of the 103-keV line in ^{153}Eu from the β decay of ^{153}Sm. The energies and intensities of 24 other lines associated with this β decay are also given. The high-energy (n, γ) spectrum, containing 23 lines between 4.5 and 5.9 MeV, was obtained with a Ge(Li) detector. The neutron binding energy of ^{153}Sm was found to be 5869.3 ± 2.0 keV. The conversion-electron spectrum, measured with the high-resolution magnetic

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spectrometer at Munich, was used to obtain K and L conversion coefficients and corresponding multipole assignments for 37 of the low-energy γ transitions. The γ spectrum in ^{153}Sm following β decay of ^{153}Pm was measured with Ge(Li) and Si(Li) detectors. The source was made at Darmstadt through the ^{154}Sm$(\gamma, p)^{153}$Pm reaction.

The (n, γ), (n, e^-), and β-decay experiments were combined to develop the level scheme of ^{153}Sm, in which unique spin and parity assignments are made for 13 of the 28 levels below 750 keV. The energy (keV) and J^π of the first 28 levels are: 0.000, $\frac{3}{2}^+$; 7.535, $\frac{5}{2}^+$; 35.843, $\frac{3}{2}^-$; 53.533, $\frac{7}{2}^+$ or $(\frac{5}{2}^+)$; 65.475, $\frac{9}{2}^+$ or $\frac{7}{2}^+$ or $\frac{5}{2}^+$; 90.874, $\frac{5}{2}^-$; 112.954, $\frac{9}{2}^+$ or $\frac{7}{2}^\pm$ or $\frac{5}{2}^\pm$; 127.298, $\frac{3}{2}^-$; 174.17, $\frac{7}{2}^-$; 182.90, $\frac{5}{2}^-$; (194.65), $\frac{5}{2}^\pm$ or $\frac{7}{2}^+$; 262.33, $\frac{7}{2}^+$ or $(\frac{5}{2}^+)$; (265.93), $\frac{7}{2}^-$ or $(\frac{5}{2}^\pm)$; 276.71, $\frac{3}{2}^+$; 321.11, $\frac{3}{2}^+$; 356.69, $\frac{5}{2}^+$; 362.29, $\frac{5}{2}^+$; (371.04), $\frac{9}{2}$ or $\frac{7}{2}$; 405.46, $\frac{3}{2}^-$; 414.91, $\frac{1}{2}^+$ or $\frac{3}{2}^+$; 447.07, $\frac{5}{2}$ or $\frac{7}{2}$; 450.04, $\frac{5}{2}$ or $\frac{7}{2}$; 481.08, $\frac{3}{2}^+$; 524.36, $\frac{5}{2}$; 630.20, $\frac{3}{2}^{(-)}$; 695.83, $\frac{1}{2}^{(+)}$ or $\frac{3}{2}^{(+)}$; 734.90, $\frac{5}{2}$; and 750.32, $\frac{1}{2}$ or $\frac{3}{2}$. The parentheses around a level energy or spin assignment mean that this value is less well established or is less probable if there is a choice. Of special interest is the very-low-energy (7.53 keV) first excited state with $J^\pi = \frac{5}{2}^+$, which appears to be the second member of the strongly distorted ground-state rotational band. A good match between the theoretical predictions of the Nilsson model and the observed γ-ray branching ratios was obtained when nine of the eleven levels below 200 keV were assigned to a positive-parity, $K = \frac{3}{2}$, ground-state rotational band and two negative-parity, $K = \frac{3}{2}$, rotational bands with band heads at 35.84 and 127.30 keV.

MASS-SPECTROMETRIC STUDY OF THE PHOTOIONIZATION OF C_2F_4 AND CF_4

T. A. Walter, C. Lifshitz, W. A. Chupka, and J. Berkowitz
J. Chem. Phys. (15 October 1969)

Photoionization-efficiency curves for CF_3^+ from CF_4 and for the parent ion and selected fragment ions from C_2F_4 are reported for the energy region from onset of ionization to about 20 eV. The ionization-efficiency curves for both parent and fragment ions from C_2F_4 demonstrate a number of very pronounced autoionization peaks. Appearance potentials are made more reliable by using a cooled ionization chamber to remove most of the thermal vibrational energy of the molecules. From the difference between the appearance potentials of CF^+ and CF_3^+ from C_2F_4, it is concluded that I. P. (CF) = I. P. (CF_3) + 0.06 eV. Therefore, the I. P. (CF) = 9.23 ± 0.08

eV can be calculated from the I. P. $(CF_3) = 9.17 \pm 0.08$ eV derived in this paper. The onset of CF_3 from CF_4 is asymptotic, and there is no clear threshold. An upper limit for this threshold was set at 15.35 eV.

OPTICAL-MODEL ANALYSIS OF NUCLEON SCATTERING FROM 1p-SHELL NUCLEI BETWEEN 10 AND 50 MeV

B. A. Watson, P. P. Singh,* and R. E. Segel

Phys. Rev. (20 June 1969)

Differential cross sections for protons scattered from B^{10} were measured and, combined with published differential cross sections and polarizations for protons elastically scattered from Li^6, Li^7, Be^9, B^{10}, B^{11}, C^{12}, C^{13}, N^{14}, and O^{16} at bombarding energies between 10 and 50 MeV, are analyzed in terms of the optical model. An investigation of the systematic effects observed in applying the optical model to light nuclei reveals two peculiarities. First, an examination of the effects of a nonlocal potential indicates that the radius parameter of the real central potential is energy dependent. Second, the Thomas form usually used for the spin-orbit potential is shown to lose its surface-peaked character in the case of light nuclei; but a proposed slight modification avoids this defect. The set of parameters found to give a good description of the data over a range of incident nucleon energy and target mass was shown to be similar to the sets of parameters found to describe the nucleon scattering from heavy nuclei. Using the prescriptions for the parameters of the present study but reversing the signs of the $(N - Z)/A$ terms leads to fits of comparable quality to the differential cross sections for 14-MeV neutrons scattered from Li^7, Be^9, B^{11}, and N^{14}.

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ABSENCE OF RECOIL DOPPLER BROADENING OF THE 3367-keV TRANSITION FOLLOWING THE REACTION $^9Be(n_{th}, \gamma)^{10}Be$

K. J. Wetzel

Phys. Rev. (20 October 1969)

The 3367-keV ground-state γ-ray transition from the reaction $^9Be(n_{th}, \gamma)^{10}Be$ shows no Doppler broadening from recoil imparted by emission of γ rays populating this level. This result is

consistent with the known lifetime of this level, which is larger than the estimated slowing-down time of the recoil nucleus in the sample medium.

(d,t) AND (d,He^3) REACTIONS ON THE CALCIUM ISOTOPES

J. L. Yntema

Phys. Rev. (20 October 1969)

The Ca^{42}(d,t)Ca^{41}, Ca^{43}(d,t)Ca^{42}, Ca^{44}(d,t)Ca^{43}, Ca^{46}(d,t)Ca^{45}, Ca^{48}(d,t)Ca^{47}, Ca^{42}(d,He^3)K^{41}, Ca^{43}(d,He^3)K^{42}, and Ca^{44}(d,He^3)K^{43} reactions have been investigated at an incident deuteron energy of 22 MeV. The angular distributions have been compared with distorted-wave calculations and the spectroscopic strength has been extracted. The larger fraction of the $d_{3/2}$ strength was found in the $\frac{3}{2}^+$ states at 2.02, 0.99, 1.04, and 2.60 MeV in Ca^{41}, Ca^{43}, Ca^{45}, and Ca^{47}, respectively. Strong s-wave transitions were observed to levels at 1.96, 1.90, and 2.00 MeV in Ca^{43}, Ca^{45}, and Ca^{47}, respectively. The $\frac{5}{2}^+$ hole state at 2.67 MeV in Ca^{41} was found to be less pure than the other strong s- and d-hole states. Similarly a pronounced fractionation of the s-hole configuration among the levels at 0.982, 1.273, 1.595, and 2.73 MeV was found in K^{41} — in contrast with the other even-parity hole states in K^{41} and K^{43} (including the $\frac{1}{2}^+$ level at 0.56 MeV) which are rather pure. This splitting is attributed in part to the interaction of another $\frac{1}{2}^+$ state with the s proton hole state. Some $2p_{3/2}$ admixture was observed in each of the neutron pick-up reactions and a $2p_{1/2}$ admixture was seen in Ca^{48}. Comparison between the relative intensities of the transitions to the $\frac{3}{2}^-$ levels in Ca^{41} and Ca^{43} and the relative intensities of the (d,p) reactions to those levels suggest the admixture of core-excited configurations in the ground state of Ca^{42} and Ca^{44}. The upper limit for the $f_{7/2}$ proton admixture in the ground state of Ca^{42} was found to be $C^2S \leqslant 0.4$. The second 0^+ state in Ca^{42} is excited with about 10% of the strength of the first 2^+ state. The strength of the transitions to these four states together with those of the 4^+ and 6^+ states is significantly smaller than expected from simple shell-model considerations and suggests that other levels with $(f_{7/2})^2$ configurations exist in Ca^{42} at higher energies. The $\ell=0$ transitions to states in Ca^{42} rarely mix with the $\ell=2$ transitions. There is a fairly good correspondence between the s-hole states and the 3^- states. Application of the sum rule and comparison with the other reactions suggests that the total spectroscopic factor for $s_{1/2}$, T = 1 pickup is considerably smaller than would be expected from a closed 2s shell. The four lowest levels in K^{42} have $\ell=2$ transitions and the

strengths are in agreement with a 2^-, 3^-, 4^-, 5^- sequence. In addition, s proton hole states in K^{42} were observed at 1.2, 2.01, and 2.13 MeV. A possible $d_{5/2}$ hole state was found in K^{41} at an excitation energy of 3.566 MeV.

IV. PUBLICATIONS SINCE THE LAST REPORT

PAPERS AND BOOKS

PHOTOIONIZATION OF HIGH-TEMPERATURE VAPORS. V. CESIUM HALIDES; CHEMICAL SHIFT OF AUTOIONIZATION
J. Berkowitz
J. Chem. Phys. 50, 3503-3512 (15 April 1969)

PHOTOIONIZATION OF HIGH-TEMPERATURE VAPORS. VI. S_2, Se_2, AND Te_2
J. Berkowitz and W. A. Chupka
J. Chem. Phys. 50, 4245-4250 (15 May 1969)

LEVEL STRUCTURE OF LOW-LYING EXCITED STATES OF Ga^{66} POPULATED BY THE DECAY OF 2.2-h Ge^{66}
H. H. Bolotin and D. A. McClure
Phys. Rev. 180, 987-996 (20 April 1969)

ELECTROMAGNETIC TRANSITION STRENGTHS IN Pb^{206}, Pb^{207}, AND Pb^{208} FROM THRESHOLD PHOTONEUTRON CROSS-SECTION MEASUREMENTS
C. D. Bowman,* B. L. Berman,* and H. E. Jackson
Phys. Rev. 178, 1827-1836 (20 February 1969)

MÖSSBAUER EFFECT IN 7.2-yr Ba^{133}
A. J. F. Boyle and G. J. Perlow
Phys. Rev. 180, 625-626 (10 April 1969)

NEUTRON-CAPTURE GAMMA-RAY STUDIES OF THE LEVEL STRUCTURE OF THE Te^{124} NUCLEUS
D. L. Bushnell, R. P. Chaturvedi, and R. K. Smither
Phys. Rev. 179, 1113-1133 (20 March 1969)

MAGNETIC MOMENT OF THE FIRST EXCITED STATE IN ^{83}Kr BY THE MÖSSBAUER EFFECT
L. E. Campbell, G. J. Perlow, and M. A. Grace†
Phys. Rev. 178, 1728-1731 (20 February 1969)

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*Lawrence Radiation Laboratory, University of California, Livermore, California.

†Nuclear Physics Laboratory, Oxford University, England.

HYPERFINE STRUCTURE AND g_J VALUES OF LOW LEVELS OF ^{159}Tb
W. J. Childs and L. S. Goodman
J. Opt. Soc. Am. 59, 875 (July 1969)

DISTRIBUTION OF CHARGE IN Th^{232} AND U^{238} DETERMINED BY MEASUREMENTS ON MUONIC x RAYS
R. E. Coté, W. V. Prestwich, A. K. Gaigalas,* S. Raboy,* C. C. Trail,† R. A. Carrigan, Jr.,‡ P. D. Gupta,‡ R. B. Sutton,‡ M. N. Suzuki,‡ and A. C. Thompson‡
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$B^{11}(He^3,\alpha)B^{10}$ REACTION AT 33 MeV
D. Dehnhard, N. Williams, and J. L. Yntema
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John R. Gabriel (Applied Mathematics) and Duane Olson
Nucl. Instr. Methods 70(2), 209-212 (15 April 1969)

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R. E. Holland
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David R. Inglis
Phys. Today 22(6), 29-40 (June 1969)

DELBRÜCK SCATTERING OF 10.8-MeV γ RAYS
H. E. Jackson and K. J. Wetzel
Phys. Rev. Letters 22, 1008-1010 (12 May 1969)

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*State University of New York at Binghamton, New York.

†Brooklyn College, The City University of New York, Brooklyn, New York.

‡Carnegie-Mellon University, Pittsburgh, Pennsylvania.

§North-Holland Publishing Co. and John Wiley & Sons, 1969.

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Peter B. Kahn* and N. Rosenzweig
J. Math. Phys. 10, 707-715 (April 1969)

MÖSSBAUER ISOMER SHIFT IN ^{243}Am
G. M. Kalvius (Solid State Science), S. L. Ruby, B. D. Dunlap (Solid State Science), G. K. Shenoy (Solid State Science), D. Cohen (Chemistry), and M. B. Brodsky (Metallurgy)
Phys. Letters 29B(8), 489-490 (21 July 1969)

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R. D. Lawson and J. M. Soper†
Nucl. Phys. A133(2), 473-480 (1969)

POSSIBLE SPIN DEPENDENCE IN PROTON INELASTIC SCATTERING
J. C. Legg‡ and J. L. Yntema
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H. J. Lipkin,§ W. I. Weisberger,§ and M. Peshkin
Ann. Phys. (N.Y.) 53, 203-214 (June 1969)

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James J. MacKenzie
Phys. Rev. 179, 1002-1010 (20 March 1969)

MULTIPOLE ANALYSIS OF PARTICLE-PARTICLE OR PARTICLE-HOLE MULTIPLETS
M. Moinester,‖ J. P. Schiffer, and W. P. Alford‖
Phys. Rev. 179, 984-995 (20 March 1969)

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J. E. Monahan
Science Progress 57, 278-279 (Summer 1969)

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*State University of New York at Stony Brook, New York and Weizmann Institute of Science, Rehovoth, Israel.

†Weizmann Institute of Science, Rehovoth, Israel and U.K.A.E.A., Harwell, Didcot, Berks., England.

‡Kansas State University, Manhattan, Kansas.

§Weizmann Institute of Science, Rehovoth, Israel.

‖Nuclear Structure Research Laboratory, University of Rochester, New York.

¶Oxford University Press, New York, 1968.

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F. P. Mooring, J. E. Monahan, and R. E. Segel
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J. A. Nolen, Jr., and J. P. Schiffer
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H. Ohnuma and J. L. Yntema
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H. Ohnuma and J. L. Yntema
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STUDY OF THE $Zr^{94}(He^3,d)Nb^{95}$ REACTION
H. Ohnuma and J. L. Yntema
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I. Pelah (Solid State Science) and S. L. Ruby
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Murray Peshkin
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PRECISION DETERMINATION OF THE D-T NEUTRON SEPARATION ENERGY
W. V. Prestwich and G. E. Thomas
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DISPERSION OF ATOMIC GYROMAGNETIC RATIOS—APPROACH TO STATISTICAL EQUILIBRIUM
N. Rosenzweig and B. G. Wybourne (Chemistry)
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J. P. Schiffer, J. A. Nolen, Jr., and N. Williams
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B. A. Watson, P. P. Singh,* and R. E. Segel
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K. J. Wetzel
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C. I. Wynter,† J. Hill,† W. Bledsoe,† G. K. Shenoy (Solid State Science), and S. L. Ruby
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E. L. Sprenkel-Segel
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*Indiana University, Bloomington, Indiana.

†A & T State University of North Carolina, Greensboro, No. Carolina.

1969 Particle Accelerator Conference—Accelerator Engineering and Technology, Washington, D.C., 5-7 March 1969

A LOW POWER MAGNETIC CHANNEL WITH DIPOLE COMPENSATION
T. Khoe (Accelerator Division), R. Benaroya (Chemistry), J. J. Livingood, W. J. Ramler (Chemistry), and W. Wesolowski (Chemistry)
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D. L. Auton, B. Zeidman, H. T. Fortune, J. P. Schiffer, and R. C. Bearse
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H. H. Bolotin, M. G. Strauss (Electronics), and D. A. McClure
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D. J. Buss and R. K. Smither
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J. R. Comfort, H. T. Fortune, G. C. Morrison, and B. Zeidman
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STUDY OF (α,t) REACTIONS ON 1p-SHELL NUCLEI
H. T. Fortune, D. Dehnhard, R. H. Siemssen, and B. Zeidman
Bull. Am. Phys. Soc. 14, 487 (April 1969)

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DELBRÜCK EFFECT IN ELASTIC SCATTERING OF 10.8-MeV γ RAYS
H. E. Jackson and K. J. Wetzel
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ISOMER SHIFT OF THE NUCLEAR γ-RAY RESONANCE (NGR) IN ^{243}Am
G. M. Kalvius (Solid State Science), S. L. Ruby, B. D. Dunlap (Solid State Science), G. K. Shenoy (Solid State Science), D. Cohen (Chemistry), and M. B. Brodsky (Metallurgy)
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LIFETIME OF THE 11-keV LEVEL IN Cs^{134m}
F. J. Lynch and L. E. Glendenin (Chemistry)
Bull. Am. Phys. Soc. 14, 629 (April 1969)

STUDY OF THE (He^3, d) REACTION FOR $A \approx 31$
Richard A. Morrison
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J. A. Nolen, Jr.,* and J. P. Schiffer
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R. H. Siemssen, H. T. Fortune, J. L. Yntema, and A. Richter
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R. K. Smither, D. J. Buss, L. M. Bollinger, and G. E. Thomas
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STATES OF Pd^{106} FROM AVERAGE RESONANCE CAPTURE IN $Pd^{105}(n, \gamma)Pd^{106}$
G. E. Thomas and L. M. Bollinger
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*University of Maryland, College Park, Maryland.

APS, Washington, D.C. (cont'd.)

COMPUTER-CONTROLLED MULTIPLE-DETECTOR SYSTEM FOR HEAVY-ION SCATTERING EXPERIMENTS
J. W. Tippie (Applied Mathematics), J. Bicek, H. T. Fortune, R. H. Siemssen, and J. L. Yntema
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METHOD FOR DWBA CALCULATION OF STRIPPING TO UNBOUND STATES
C. M. Vincent and H. T. Fortune
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METHOD FOR DETERMINING SPINS OF NEUTRON RESONANCES
K. J. Wetzel, G. E. Thomas, L. M. Bollinger, and H. E. Jackson
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ANGULAR DISTRIBUTIONS OF HEAVY IONS PRODUCED BY ^{3}He BOMBARDMENT OF ^{12}C
B. Zeidman and H. T. Fortune
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A SYSTEMS APPROACH TO THE NUCLEAR SHELL MODEL
Stanley Cohen
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EFFECT OF CHANNELING ON THE CHARGE-CHANGING COLLISIONS OF ENERGETIC DEUTERONS PENETRATING THROUGH Ni(110) MONOCRYSTALS
M. Kaminsky
Bull. Am. Phys. Soc. 14, 846 (August 1969)

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A SURVEY OF SINGLE-PARTICLE AND COLLECTIVE STATES IN THE ACTINIDES BY USE OF TRANSFER REACTIONS
A. M. Friedman (Chemistry), J. R. Erskine, T. H. Braid, and R. R. Chasman (Chemistry)
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Chemistry and Physics Staff
Argonne National Laboratory Topical Report ANL-7582 (June 1969)

PHYSICS DIVISION INFORMAL REPORTS

AN INTRODUCTION TO SPEAKEASY
S. Cohen and C. M. Vincent
Physics Division Informal Report PHY-1968E (December 1968)

ANALOG RESONANCES IN HEAVIER NUCLEI
Malcolm H. Macfarlane
Physics Division Informal Report PHY-1969D (June 1969)

LOW-LYING LEVELS IN SOME SPHERICAL AND ROTATIONAL NUCLIDES BY COULOMB EXCITATION AND RADIATIVE CAPTURE OF THERMAL NEUTRONS
Donald A. McClure
Physics Division Informal Report PHY-1969E (August 1969)
Ph.D. Thesis, University of Missouri - Rolla (August 1969)

PROTON-INDUCED ANALOG RESONANCES
George C. Morrison
Physics Division Informal Report PHY-1969C (April 1969)

STUDENT REPORTS

A STUDY OF THE $Mg^{24}(p,\alpha)$ REACTION
Richard L. Boudrie
CSUI-ANL student report to Western Michigan University (Spring 1969)

ANALYSIS OF CONVERSION-ELECTRON DATA
Richard H. Heisterberg
ACM student report to Knox College (September 1969)

COMPLEX IMPEDANCE OF RADIOFREQUENCY PLASMAS
William S. Paciesas
CSUI-ANL student report to Seton Hall University, South Orange, New Jersey (Spring 1969)

ANALYSIS OF MULTIPARAMETER GAMMA-GAMMA COINCIDENCE DATA WITH THE IBM-360 COMPUTER
W. R. Western
Summer Student Trainee report to Cornell College, Mount Vernon, Iowa (15 August 1969)

V. PERSONNEL CHANGES IN THE ANL PHYSICS DIVISION

NEW MEMBERS OF THE DIVISION

Visiting Scientists (Summer)

Dr. Hendrik DeWaard, University of Groningen, Netherlands. Mössbauer effect in ^{67}Zn. Came to Argonne on 30 June 1969.

Dr. Paul Kienle, Technische Hochschule München, Germany. Charged-particle experiments at the Tandem. Returned to Argonne on 1 August 1969.

Dr. Thomas T. S. Kuo, State University of New York at Stony Brook. Nuclear structure and nucleon-nucleon interaction; structure of the analog and antianalog states. Returned to Argonne on 30 June 1969.

Dr. Harry J. Lipkin, Weizmann Institute of Science, Rehovoth, Israel. Symmetries, quark models, and duality in particle physics. Returned to Argonne on 16 June 1969.

Dr. Igal Talmi, Weizmann Institute of Science, Rehovoth, Israel. Coulomb energies in nuclei and the relationship between particle-particle and particle-hole spectra. Came to Argonne on 16 June 1969.

Resident Associates

Dr. George B. Beard, Wayne State University, Detroit, Michigan. Doppler-shift lifetime measurements; Coulomb excitation. (CEA affiliate, Faculty Research Participation Program.) Returned to Argonne on 14 July 1969.

Dr. David Gutman, Illinois Institute of Technology, Chicago. Microscopic kinetics of ion-molecule reactions studied by use of photoionization mass spectrometry. (CEA affiliate, Faculty Research Participation Program.) Came to Argonne on 15 September 1969.

Dr. Paul-Marie Guyon, Laboratoire de Collisions Electroniques, Orsay, Essone, France. Study of the direct and dissociative photoionization of small molecules (HF, DF, H_2CO, HDCO, D_2CO). (CEA affiliate, Faculty Research Participation Program.) Came to Argonne on 1 July 1969.

Dr. Harry G. Miller, Defiance College, Defiance, Ohio. Measurements of internal-conversion coefficients of thermal-neutron-capture gamma-ray transitions. (CEA affiliate, Faculty Research Participation Program.) Came to Argonne on 3 September 1969.

Resident Associates (Summer)

Dr. David Bushnell, Northern Illinois University, DeKalb. Level structure of ^{180}Hf. (CEA affiliate, Faculty Research Participation Program.) Returned to Argonne on 2 June 1969.

Dr. John G. Stevens, University of North Carolina at Asheville. Mössbauer studies. (CEA affiliate, Faculty Research Participation Program.) Returned to Argonne on 2 June 1969.

Resident Student Associate (Thesis)

Mr. Abdelhadi S. Yousef, graduate student, Illinois Institute of Technology, Chicago. Working with E. Segel on investigation of the $^{7}Be(p,\gamma)^{8}B$ reaction at very low energies. (CEA affiliate.) Came to Argonne on 1 July 1969.

Resident Student Associate (Summer)

Mr. Paul J. Dawson, graduate student, Illinois Institute of Technology, Chicago. Working with R. Segel on search for parity nonconservation in the alpha decay of the 8.88-MeV state in ^{16}O. (CEA affiliate, Graduate Student Research Participation Program.) Came to Argonne on 31 July 1969.

AUA-ANL Predoctoral Fellowship

Mr. George H. Wedberg, Jr., graduate student, Indiana University, Bloomington. Working with R. E. Segel on Doppler-shift measurements of nuclear lifetimes. Came to Argonne on 23 June 1969.

Student Aides (ACM)

Mr. Martin E. Dybicz, Knox College, Galesburg, Illinois. Working with S. B. Burson on analysis of gamma-ray spectroscopy data to determine nuclear decay schemes; design work for making a high-quality thermal neutron beam at the CP-5 reactor. Came to ANL on 1 July 1969.

Mr. Carey S. Inouye, Ripon College, Ripon, Wisconsin. Working with G. C. Morrison on deuteron-induced reactions on ^{26}Mg, ^{27}Al, and ^{28}Si. Came to ANL on 1 July 1969.

Mr. Lawrence W. Panek, Lawrence University, Appleton, Wisconsin. Working with G. J. Perlow on computer calculations with the Wilson-Froese HFSCF program to obtain electron densities at the iridium nucleus for a variety of configurations in various ionization states. Came to ANL on 1 July 1969.

CSUI-ANL Honor Students

Mr. Richard Adams, Temple University. Working with G. C. Morrison on the analysis of ^{6}Li-^{6}Li elastic scattering at 12, 20, and 28 MeV. Came to ANL on 2 September 1969.

Mr. Walter S. Jaronski, St. Peter's College, Jersey City, New Jersey. Working with L. S. Goodman on atomic-beam research. Came to ANL on 2 September 1969.

Mr. Robert J. Pangborn, Albion College, Albion, Michigan. Working with S. L. Ruby on the Mössbauer effect in ^{129}I as an inclusion product in amylose and cyclodextrins. Came to ANL on 2 September 1969.

Mr. Howard A. Walter, Jr., St. Lawrence University, Canton, New York. Working with J. Berkowitz on construction of an electrostatic electron energy analyzer; computer-aided design of energy analyzers. Came to ANL on 2 September 1969.

Mr. Robert E. Zeman, St. Peter's College, Jersey City, New Jersey. Working with R. H. Siemssen on optical-model analysis of heavy-ion elastic-scattering data. Came to ANL on 2 September 1969.

Summer Student Training Program

Mr. Jerry R. Becker, Bethel College, North Newton, Kansas. Working with T. H. Braid on charged-particle detection and analysis. Came to ANL on 9 June 1969.

Mr. Eugene F. Chaffin, Oklahoma State University, Stillwater, Oklahoma. Working with W. A. Chupka on study of photoionization by use of a mass spectrometer. Came to ANL on 9 June 1969.

Mr. Robert W. Gerlach, Case-Western Reserve University, Cleveland, Ohio. Working with R. S. Preston on the Mössbauer effect. Came to ANL on 9 June 1969.

Mr. Steven Goldstein, Carleton College. Working with L. S. Goodman on the atomic-beam magnetic-resonance apparatus. Came to ANL on 9 June 1969.

Mr. John R. Kender, University of Detroit, Detroit, Michigan. Working with L. Meyer-Schützmeister on nuclear spectroscopy. Came to ANL on 9 June 1969.

Mr. Warren R. Western, Cornell College, Mount Vernon, Iowa. Working with H. H. Bolotin on analysis of multiparameter gamma-gamma coincidence data with the IBM-360 computer. Came to ANL on 9 June 1969.

Mr. Louis E. Willhoit, Jr., Florida State University, Tallahassee. Working with R. H. Siemssen on data analysis of charged-particle interactions on the tandem Van de Graaff accelerator. Came to ANL on 9 June 1969.

Technician

Mr. Anthony C. Jackson joined the Physics Division on 7 July 1969 to work with S. L. Ruby.

LEAVE OF ABSENCE

Dr. Dieter Kurath left ANL on 1 September 1969 to go to the State University of New York at Stony Brook as a visiting professor of physics. He expects to return to Argonne in August 1970.

RETIREMENT

Dr. Carl T. Hibdon has been on the staff of the ANL Physics Division since 21 June 1948. He has worked on internally converted gamma rays; neutron scattering around the reactor CP-3'; neutron cross sections; level structure of light nuclei. He terminated at ANL on 31 August 1969.

DEPARTURES

Dr. David L. Auton, student associate (thesis, CEA affiliate) from the University of Chicago has been in the Physics Division since 5 June 1967. He has worked on direct reactions on ^{10}Be. He terminated at ANL on 24 April 1969.

Dr. Robert C. Bearse has been on the staff of the ANL Physics Division since 1 September 1966. He has worked on the giant dipole resonance; gamma decay of $T=\frac{3}{2}$ states; and Doppler-shift lifetime measurements. He terminated at ANL on 29 August 1969 to go to the University of Kansas, Lawrence, Kansas.

Dr. Lawrence E. Conroy, resident associate (CEA affiliate, Faculty Research Participation Program) from the University of Minnesota has been in the Physics Division since 17 March 1969. He has worked on chemical aspects of the Mössbauer effect, particularly on the recoil-free fraction for a sodium-tungsten bronze. He terminated at ANL on 12 September 1969 to return to the University of Minnesota.

Dr. H. T. Fortune, postdoctoral, has been in the Physics Division since 5 September 1967. He has worked on charged-particle experiments at the tandem and cyclotron. He terminated at ANL on 29 August 1969 to go to the University of Pennsylvania, Philadelphia.

Dr. Walter Henning, research associate from Technische Hochschule München, Germany, has been in the Physics Division since 17 January 1969. He has worked on measurements of the hyperfine anomaly in ^{193}Ir by use of the Mössbauer effect; calculations of Coriolis mixing in deformed odd-A nuclei. He terminated at ANL on 1 April 1969 to return to the Technische Hochschule München.

Dr. David R. Inglis has been on the staff of the ANL Physics Division since 1 September 1949. He has worked on theoretical studies of nuclear structure and deformations—including intermediate coupling in the shell model of light nuclei and, in heavier nuclei, fission and the cranking model of rotation; nuclear reactions, scattering, and radiations; experimental studies with a magnetic spectrometer; scientific aspects of disarmament and weapons control. He terminated at ANL on 3 September 1969 to go to the University of Massachusetts, Amherst, Massachusetts.

Mr. Michael M. Korter, engineering technician, has been in the Physics Division since 7 August 1967. He terminated at ANL on 23 May 1969.

Dr. Kiuck Lee, resident associate (CEA affiliate) from Marquette University, Milwaukee, Wisconsin, has been in the Physics Division since 8 July 1968. He has worked on the theory of fission of deformed nuclei. He terminated at ANL on 18 September 1969 to return to Marquette University.

Dr. Donald A. McClure, AUA-ANL Predoctoral Fellow from the University of Missouri at Rolla, has been in the Physics Division since 15 June 1967. He has worked on low-lying levels in some spherical and rotational nuclides by Coulomb excitation and radiative capture of thermal neutrons. He terminated at ANL on 20 August 1969 to go to the Georgia Institute of Technology, Atlanta, Georgia.

Dr. Richard A. Morrison, student associate (thesis, CEA affiliate) from the University of Chicago has been in the Physics Division since 5 June 1967. He has worked on a study of nuclei with masses near 32 with the (^{3}He,d) reaction. He terminated at ANL on 30 June 1969 to go to Talladega College, Talladega, Alabama.

Mr. Stasys V. Rastonis, scientific technician, has been in the Physics Division since 16 July 1968. He terminated at ANL on 3 July 1969.

Mr. Edwin Sinars, engineering technician, has been in the Physics Division since 27 November 1967. He terminated at ANL on 22 August 1969.

Dr. Theodore A. Walter, postdoctoral, has been in the Physics Division since 17 April 1967. He has worked on photoionization studies with mass analysis. He terminated at ANL on 16 May 1969 to go to The National Institute of Mental Health, Laboratory of Clinical Science, Bethesda, Maryland.

Dr. Karl J. Wetzel, postdoctoral, has been in the Physics Division since 15 November 1967. He has worked on determination of spins of neutron resonances; study of high-energy γ-ray line shape (Doppler recoil broadening of secondary transitions in γ-ray cascades); average radiation widths from neutron capture in manganese and vanadium; Delbrück and Raman scattering of 10.8-MeV γ rays. He terminated at ANL on 15 August 1969 to go to the University of Portland, Portland, Oregon.

Dr. G. Theodore Wood has been on the staff of the ANL Physics Division since 2 August 1965. He has worked on gamma-gamma angular correlations in magnetic materials; conversion-electron spectroscopy with the six-gap beta-ray spectrometer. He terminated at ANL on 26 September 1969 to go to The Cleveland State University, Cleveland, Ohio.

DECEASED

Mr. Gordon Goodwin, scientific technician, who had been in the ANL Physics Division since 22 January 1962, died on 18 July 1969.

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